THE PESTICIDES CONSUMER-ENVIRONMENTAL INDEXING SYSTEM

PROJECT STUDY REPORT

2021

THREE PERCENT EARTH FOUNDATION

This project study was conducted as a key part of Three Percent Earth Foundation's mission to address the potential and realised impact(s) associated with pervasive and systematic use of crop protection chemicals as convention in commercial agricultural production throughout Southeast Asia.
In tackling the issue, the aim of the project study centred on two basic factors germane to pesticides-related health risk(s) and environmental impacts. First, the role of commercial agricultural production systems in modern global food security , and second, reliance on the use of chemical pesticides within these systems, and its capacity to contaminate soil, water, air, and food commodities leading to potential human exposure.

The original working draft of this policy research project was organised in peer-review format, and completed 10 May 2021. This working paper reconfigures the project study in report form.

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Three Percent Earth Foundation © 2019 is a not-for-profit, research-based civil society organisation whose mission is to help advance the cause of sustainable development for the benefit and betterment of all communities throughout the Southeast Asia (ASEAN) region, by raising awareness of human impacting activities associated with agricultural pesticides use, and consumer-industrial pollution; and to emphasise the need for practical, and effective governance and policy solutions to help reduce and/or prevent impacts to health and environment.

The working office of Three Percent Earth Foundation is located in Pakkret, Nonthaburi, Thailand. To inquire about the organisation, and its mission please go to www.threepercentearth.org

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ABBREVIATIONS

EIQ	Environmental Impact Quotient
EIR-IS	Exposure Indicator Ratio-Index Score
EIR_{score}	Exposure Indicator Ratio Score
EPI	Environmental Performance Index
ERI	Exposure Ratio Index
ERI_{max}	Exposure Ratio Index Maximum
ERI_{min}	Exposure Ratio Index Minimum
ERIP	Exposure Ratio Index Percent
ERIQ	Exposure Ratio Index Quotient
ERI-TD	Exposure Ratio Index Threshold Difference
FLAC	Farmland Area per capita
G20	Group of Twenty
G7	Group of Seven
g-AEES	Generalisable Agro-Economic Environmental System
GAP	Good Agricultural Practices
GDP	Gross Domestic Product
GUS	Groundwater Ubiquity Score
HELI	Health and Environment Linkages Initiative
IPM	Integrated Pest Management
OECD	Organisation for Economic Co-operation and Development
PCE-IS	Pesticides Consumer-Environmental-Index Score
PCE-ISys	Pesticides Consumer-Environmental Indexing System
PCPr	Pesticides-to-Crop Productivity Ratio
PERI	Pesticide Environmental Risk Indicator
Pi_{exp}	Pesticides Exposure Indicator
$Pi_{exp}R$	Pesticides Exposure Indicator Ratio
$Pi_{exp}UC$	Unit-converted Pesticides Exposure Indicator

Pi_{ref}	Pesticides Reference Indicator
$Pi_{ref}R$	Pesticides Reference Indicator Ratio
$Pi_{ref}UC$	Unit-converted Pesticides Reference Indicator
SDG	Sustainable Development Goal
FAO	Food and Agriculture Organization of the United Nations
UNEP	United Nations Environment Programme
WHO	World Health Organization

EXECUTIVE SUMMARY

This project study report was undertaken by Three Percent Earth Foundation to address the on-going issue of global agricultural (chemical) pesticides use, and its associated health and environmental impacts to all worldwide communities, including ASEAN.
During the mid-twentieth century increasing global population growth, and food demand helped create the impetus for the green revolution, an agricultural and economic policy initiative aimed at ending food hunger throughout the developing world. Producing sufficient crop and food output for millions of people (over a relatively short-term) necessitated a shift from subsistence farming methods of the past to mostly large-scale, land and resource-intensive agricultural practices. Today, the aim of global food security is set forth in United Nations Sustainable Development Goal 2, termed 'Zero Hunger.'

High-intensity, commercial mono-culture farming processes have been, and continue to be accompanied by the adoption of seemingly more cost-effective (chemical) crop protection methods leading to measurable increases in harvested yields, and food production for low-to-middle income nations. The perceived and realised social, and economic benefits derived from widespread chemical pesticides-use, however, have since been tempered by a continuing stream of empirical and anecdotal evidence of the health and environmental effects linked to exposure(s).

Globally at present, hyper-focused, economic development-orientated governance regimens that largely dictate agricultural systems of production have resulted in a strong propensity for population-level chemical pesticides exposure(s), with conventional agroeconomic policy and decision-making often failing to take into account the environmental and public health consequences of residual pesticides concentration(s) found in commercial food products, as well as almost certain contamination of air, soil, and water.

Pesticides regulated worldwide chiefly centre on heuristically-guided, risk-based methods of quantitation that extrapolate cellular, and/or animal-based toxicity study results, which presuppose 'safe,' or 'acceptable' human exposure levels. A disconcerting abundance of human epidemiological evidence highlighting chemical pesticides risk, however, point to the limitations of an economically-focused, health-based regulatory paradigm; One that perhaps warrants reconsideration of how public health and environment are viewed within global economic systems.

THE PESTICIDES CONSUMER-ENVIRONMENTAL INDEXING SYSTEM

The following project study involves the development and application(s) of a novel macro-indicator-based approach to indexing potential exposure to chemical agricultural pesticides within the context of 'generalisable' agroeconomic-environmental systems i.e., g-AEES (by country). The indexing construct supports the argument for a methodology that can 'screen' a relative estimation of potential exposure, and the magnitude of such exposure as a new, alternative course to environmental policy decision-support that ostensibly works to harmonise public health with agricultural economy.

The Pesticides Consumer-Environmental Indexing System (PCE-ISys) is a semi-quantitative evaluation model purposed to provide a data-driven screening of the potential exposure-related implication(s) associated with collective macro-level economic policy decisions that impact key crop protection chemical-related inputs used throughout agricultural industry.

The evaluation scheme is based on the principal assumption that the potential for population-level exposure together with the magnitude of potential exposure (per capita), i.e., 'total exposure potential' arises from the summation use of pesticides across the broader system of crop cultivation, food production, trade, consumption, and environment.

The rationale for the indexing scheme is based on the idea that substantially limiting, or preventing potential exposure(s) from the perspective of collective, 'macro-level' policy decisions are central to reducing pesticides related impact(s).

As an 'upstream' screening-level, decision-support tool the functional framework for PCE-ISys implicitly relies on select macro-indicator (variables) that help characterise global generic systems of agricultural economy (g-AEES),

- Total average annual pesticides consumption rate (by country)
- Annual Crop Production Index (by country)
- Total estimated agricultural land (by country)
- Total estimated population (by country)

Because indexing is largely a gage of relative estimated outcome(s) data representing each select indicator is (by necessity) transformed from continuous variable to a range of measure captured by discrete value(s). In the case of PCE-ISys the distribution of continuous data values are conformed to fall within three percentile categories,

- Upper 25%th percentile = $(3(n+1)/4)^{th}$ term
- Median 50th percentile = $((n+1)/2)^{th}$ term
- Lower 25%th percentile = $((n+1)/4)^{th}$ term

which is subsequently 'coded' using discrete values, 1-, 3-, or 5. The magnitude of discrete values (or the 'direction of magnitude') are based on how each respective indicator variable is assumed to 'behave' within the parameters of g-AEES, under an assumption of a gaussian distribution.

<u>Macro-indicator 'behaviour' assumptions within g-AEES</u>

1. Agricultural pesticides-use rate is directly related to the potential for human exposure; therefore, indicator variable data distribution is coded 5, 3, 1.

2. Total annual pesticides-use rate is a fixed average measure; therefore, crop productivity is inversely related to potential pesticides exposure, with indicator variable data distribution coded as 1, 3, 5.
3. Land used for agricultural production serves as a direct indicator for pesticides tonnage; therefore, indicator variable data distribution is coded 5, 3, 1.
4. The potential for exposure is 'diluted' with increasing population (relative to pesticides tonnage); therefore, indicator variable data distribution is coded 1, 3, 5.
5. '**Exposure Potential**' is defined as the Pesticides Reference Indicator-adjusted relative magnitude of potential daily pesticides exposure (per capita) arising from g-AEES as a function of the,

Pesticides-to-Crop Productivity Ratio (PCPr) ↓ **Farmland Area per capita (FLAC)** ↓

$$\frac{\text{Total (Annual) Pesticides Use Rate (kg/ha)}}{\text{Annual Crop Production Index}} \times \frac{\text{Total (Annual) Agricultural Land Area (ha)}}{\text{Annual Estimated Country Population}}$$

'Exposure Potential' directly increases, or decreases with the potential magnitude of daily pesticides exposure per person; therefore, the indicator variable data distribution is coded 5, 3, 1.

The main index scoring measure for PCE-ISys, termed the 'Exposure Indicator Ratio-Weighted Index Score,' or EIR-IS (by country) is expressed as the as the sum of the 'coded' values for the indicator variable data distribution values explained in items '1' through '4' added to the 'coded' value reflecting 'exposure potential.' The range of the weighted index scale (by country) is scored between 5, meaning lower total exposure potential to 25, meaning highest total exposure potential, with a time-series averaged country-specific numeric ranking constructible corresponding to the respective nation's average EIR-IS.

The **PCE-ISys Public Health Rating Scheme** is the qualitative measure used to characterise outcome(s) associated with 'total exposure potential.' It is based on three fundamental precepts,

- That chemical pesticides are engineered to produce target organism mortality, but also manifest varying degrees of 'collateral' toxicity to other biological species, including humans.
- That pesticides-related health impact(s) and risk are function(s) of pesticides exposure.
- That pesticides risk reduction through 'integrated' policy and planning measure(s), over the long-term, are best accomplished, and more cost-effective through prevention efforts, as opposed to 'command and control' impact mitigation.

PCE-ISys is not a tool designed to estimate risk or impact(s). The rating methodology is defined by a generic qualitative rating termed 'Appreciable public health concern' based on where EIR-IS (by country) falls within the index scoring distribution for each annual evaluation dataset. The scoring classification across each data distribution range are ordered according to a three-tiered percentile range: Upper 25th%ile = Highest Appreciable, Median = Appreciable, and Lower 25th%ile = Lower Appreciable, with the following index score 'cut-off' levels,

- EIR-IS ≥ 17 (Upper 25th), EIR-IS = 15 (Middle 50th), EIR-IS ≤ 13 (Lower 25th)

PCE-ISys model statistical correlation and variance was determined through standard multivariate regression methodology. The strength of correlation between the PCE-ISys weighted index, i.e., average EIR-IS (response variable), and the g-AEES indicator (input) variable demonstrated a reasonably strong association, r = 0.657789 with the model explaining nearly a 42% change in average EIR-IS. The second multivariate analysis examining the strength of correlation, and variance of average EIR-IS to 'exposure potential' also demonstrated a similarly strong association, r = 0.699048 with the model explaining nearly half the variance (48%) in average response variable output. Analysis sample sizes for both regression exercises were both n = 157.

All indicator variables for both models were statistically significant, except for 'Average Annual Estimated Country Population,' which was marginally non-statistically significant (p-value = 0.078810616); though this occurrence was not altogether unexpected given the complex and dynamic nature of human-to-environment interaction. The fact that FLAC turned out to be a statistically significant, linearly correlated variable relative to EIR-IS points to country population as a relevant indicator variable (in the context of pesticides tonnage) for interpreting pesticides total exposure potential, but at the same time difficult to elucidate through semi-quantitative indexing.

KEY FINDINGS FROM THE TESTING APPLICATION(S) OF PCE-ISys

PCE-ISys testing applications (based on applicable available data from FAO and World Bank) produced 27 evaluation datasets comprising a sample size (n) range of countries $157 \geq n \geq 133$. The number of country-specific observations (by year), including ranking profile numbers, and their associated g-AEES macro-indicator values totalled 8,278, and are available as open access at www.threepercentearth.org.

1. Among 157 nations evaluated using PCE-ISys (for the 27-year time series), Belize, with an average EIR-IS of 21.37 was rated as having the highest average pesticides total exposure potential in the world, while Mauritania, and its average EIR-IS of 9 had the lowest average total exposure potential.
2. Forty of 157 nations evaluated using PCE-ISys demonstrated average weighted index scores in line with 'highest' total exposure potential, and Highest Appreciable public health concern.

3. Among the 40 nations with 'highest' pesticides total exposure potential, nearly 38% and 23% were from the Americas and Asia-Pacific region, respectively.
4. A large swath of countries within the Americas trended higher overall in pesticides total exposure potential while a substantial number of countries throughout the African continent ranked among the lowest.
5. Average EIR-IS among nineteen G7/G20 nations was 15.49 with nearly 63% characterised as having 'high medium' to 'highest' total exposure potential.' Size of country economy alone, however, is unlikely a direct indicator of pesticides total exposure potential.
6. Italy, China, Argentina, Brazil, and France fell within the highest percentile range indicating highest pesticides total exposure potential among G7/G20 nations, and among the top forty nations with highest total exposure potential.

The PCE-ISys construct also features the capacity to index 1) pesticides total exposure potential worldwide, referred to as the 'exposure ratio index,' or ERI, where $ERI = \sum EIR\text{-}IS_{country}$ (by year), and 2) average worldwide exposure potential referred to as average global Pesticides Exposure Indicator Ratio, $Pi_{exp}R$. Some key findings were as follows,

7. Year-over-year Δ ERI for the time series (1990 – 2016) demonstrated a +16% change (or a net increase of 334 global exposure index points). Also, the ratio of countries with Appreciable and Highest Appreciable public health concern to Lower Appreciable public health concern was 1.63 to 1.
8. Average global $Pi_{exp}R$, from 1990 – 2016 increased from 9.8 to 17.43 (+78%).

CONCLUDING REMARKS

The goal of global food security à la SDG 2 need not be mutually exclusive from agroeconomic systems guided by an objective of producing sustainable whole foods characterised by reduced, or preventable pesticides risk.

The discernible limitations of a heavily profit-driven, risk-based regulatory framework should be a clear enough signal to policy makers, and other leaders that (what amounts to) unfettered pesticides-use is fundamentally counter-intuitive to how public health and ecological integrity is viewed within existing economic systems. New, more inclusive approaches that integrate public health and sustainability into economic growth and development need to be adopted for the benefit of civil society, and private sector alike.

The Pesticides Consumer-Environmental Indexing System (PCE-ISys) offers one possible, viable alternative in how society, and the state can re-evaluate agroeconomic development. By prioritising the potential for, and magnitude of pesticides exposure through a macro-policy development lens, health, environment, and economy may ostensibly be harmonised.

1 INTRODUCTION

The following project study was undertaken by Three Percent Foundation to address the prevailing global situation regarding the long-standing, pervasive, and systematic use of chemical agricultural pesticides as the primary economic input for protecting crop production yields, despite a wealth of empirical evidence demonstrating profound human health risk, and environmental impact associated with their use.

A vast body of scientific literature about pesticides exposure, and hazard potential point to a myriad of human and non-human mammalian effects that include, disruption to cellular protein, carbohydrate, and fat metabolism, genotoxic effects, cellular oxidative stress, and impacts to nervous system and endocrine function, among others. Such cellular and physiologic insults have been associated with increased risk of non-Hodgkin's Lymphoma, dementia, cardiovascular disease, decreased gestational duration, decreased male reproductive function, and childhood neurologic and development problems, to name a few. Such deleterious, long-term effects not only impair human health, but more broadly damages ecological integrity, as well as the social, and economic framework of society (Nicolopoulou-Stamati et al, 2016).

The development and use of a novel macro-indicator-based evaluation tool is designed to help address the fundamental shortcomings (or lack) of existing policy structures aimed at regulating pesticides health and safety protocols, and which govern the use of crop protection chemicals, worldwide.

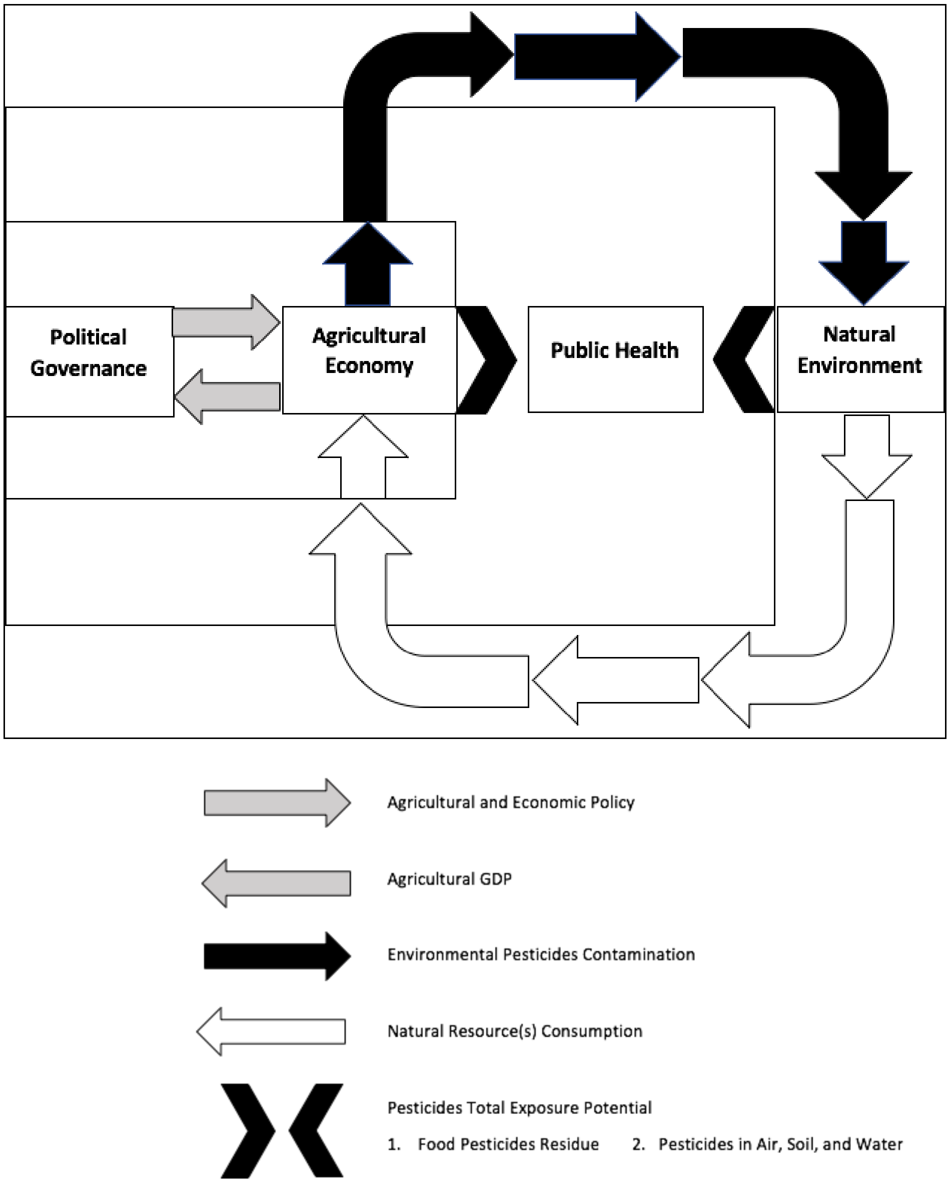
Across the 'global south,' the green revolution represented an active initiative of intensified agricultural production to meet population growth, and food demand (Paddock, 1970, Pingali, 2012). The adoption of cost-effective crop protection methods, specifically the use of chemical farming pesticides (Glass and Thurston, 1978; Pingali, 2001; Repetto, 1986; Sharma et al., 2019) led to increases in crop yield and food production for low-to-middle income nations (European Parliament, 2021; Pinstrup-Andersen, 2002; Popp et al., 2013; Popp and Hantos, 2011; Zhang, 2018). Today, the aim of global food security is set forth in UN Sustainable Development Goal 2 (United Nations Development Programme, 2021). At the same time, however, the perceived and realised economic benefits from perennial consumption of agricultural pesticides continue to be linked to evidence of risk and impact(s) to human and ecological health (European Parliament, 2021; Lam et al., 2017; Pingali, 2001; Popp et al., 2013; Popp and Hantos, 2011).

1.1 Agroeconomic Systems, Pesticides, and Human Health Risk

Development-orientated governance decisions that effectively dictate systems of agricultural economy have resulted in a strong propensity for pesticides exposure at the population-level (Aktar et al., 2009; Bonmatin et al., 2015; Economy and Environment Institute, 2017; European Parliament, 2021; Gereslassie et al., 2019; Lam et al., 2017; Pingali, 2001).

The convergence of numerous factors including, physico-chemical properties, conditions of climate, air, land, and water, as well as collective political and regulatory decision-making aimed at meeting food consumption demand and economic growth objectives all potentially influence population-based risk from combined exposure(s) to multiple high production volume chemicals such as farming pesticides (Organisation for Economic Co-operation and Development, 2018) commonly used within (highly complex) social-environmental systems of agricultural economy (Bonmatin et al., 2015; Boxall et al., 2009; Del Prado-Lu, 2015; Fernandez-Cornejo et al., 1998; Gereslassie et al., 2019; Obilo et al., 2006; Rice et al., 2007; Skevas, 2012; United Nations Environment Programme-HELI, 2004) Figure 1. illustrates a simplified diagram depicting a complex 'generalisable' agroeconomic environmental system.

Figure 1. Diagram of a 'generalisable' agroeconomic environmental system (g-AEES)



Conventional agroeconomic policy regimens often fail to factor in the environmental and public health-related consequences of likely residual pesticide(s) concentration(s) found in food commodities, as well as almost certain contamination of air, soil, and water (Aktar et al., 2009; European Parliament, 2021; Kennedy et al., 2019; Obilo et al., 2006).

1.2 Indexing as a Policy Decision-Support Tool

Policy decision-support is an essential informational component for guiding governance-based decision making such as addressing the role of agriculture in achieving economic goals tied to food production, trade, and consumption (Lencucha et al., 2020; Rose et al., 2016; Udias et al., 2018).

Indicator and indexing methods offer a heuristic approach to evaluating relevant data in support of specific or broad policy goals (Corporate Finance Institute, 2021; Gorai and Goyal, 2015; Sherrick, 2017; Surminski and Williamson, 2012; World Bank, 2021). For pesticides this type of evaluation device is principally designed to comparatively examine, score, or rank chemicals, or chemical-related outcomes. Many pesticides scoring frameworks are designed to index based on physico-chemical, environmental, and/or health related parameters (Benbrook and Davis, 2020; Chou et al., 2019; Kookana et al., 2005; Reus et al., 2002; Van Bol et al., 2005; Van Bol et al., 2003).

The environmental impact quotient (EIQ) used in support of integrated pest management (IPM) is a risk-based indexing system that ranks individual pesticides using a simple numeric (5=high, 3=medium, 1=low) coding system corresponding to pesticide-specific toxicological, and physico-chemical reference values in the context of three classes of receptor with potential for exposure, i.e., worker, consumer, and ecological (Kovach et al, 1992). Similarly, the pesticide environmental risk indicator model (PERI) an evaluation criteria component of ISO-14001 certification for farm-level decision making is a scoring system that takes into account the groundwater ubiquity score (GUS), i.e., the measure of a pesticide's proclivity to contaminant groundwater sources, as well as ecological toxicity reference values, and K_{ow} (a surrogate measure of a chemical's ability to partition biological membrane) (Muhammetoglu et al., 2010). Both indexes have proven utility in guiding decisions about pesticides use with consideration for risk reduction (Kromann et al., 2011; Soudani et al., 2020).

Some indexing models are strictly data-driven in methodology, while others are based on a representation of multivariable complex 'systems.' Li et al. (2019), used the decoupling index (a purely data-driven approach originally used by OECD for analysing (non-synchronous) relationships between economy and carbon emissions) to address the 'connectivity' between agricultural economy and agricultural pollution. The environmental performance index (EPI) addresses economy and environmental outcomes (on a global scale) by scoring and ranking the overall environmental sustainability of 180 countries. The index does so by aggregating, and/or statistically modelling data from 32 separate sustainability indicators across two broad evaluation categories, 'ecological vitality,' and 'environmental health,' and then using the index outputs to assess the status of health and environment in relation to macroeconomic indicators such as GDP (Wendling et al, 2020).

The use of index methods as a policy decision-support tool for addressing inherently complex issues of health and environment offer regulators, policy makers, farmers, and civil society a reasonably transparent evaluation approach by which to draw practical conclusions about risk reduction guidance measures, and strategies for achieving health-protective goals as a part of the broader social-economic framework (Choi et al., 2019; Gorai and Goyal, 2015; Kookana et al., 2005; Kovach et al., 1992; Kromann et al., 2011; Wendling et al., 2020).

2 PESTICIDES CONSUMER-ENVIRONMENTAL INDEXING SYSTEM

The aim of this project study is to introduce and discuss the development, and practical application(s) of the *Pesticides Consumer-Environmental Indexing System* (PCE-ISys), a novel policy decision-support tool that quantifies, scores, and ranks (on a global scale) 'total exposure potential' defined as the potential for human exposure to, and the magnitude of potential exposure from agricultural pesticides within the context of a system of interconnected economy and environment.

2.1 Rationale Supporting PCE-ISys

PCE-ISys is a semi-quantitative evaluation model purposed to provide a data-driven screening of the potential exposure related implications associated with macro-level economic policy decisions that impact agricultural pesticides use, and pesticides-related farming inputs and outcomes.

*The PCE-ISys evaluation scheme is based on the principal assumption that the potential for population-level exposure together with the magnitude of potential exposure, i.e., '**total exposure potential**' arises from the summation use of pesticides across the broader system of crop cultivation, food production, trade, consumption, and environment.*

The PCE-ISys concept works by indexing the potential for pesticides exposure, and quantifying and indexing the magnitude of potential exposure on a 'per capita' basis. The rationale for the indexing scheme is based on the idea that substantially limiting, or preventing potential exposure at the macro-level is key to reducing pesticides related impact(s), which can happen when consideration is given to harmonising measures of public health with collective policy decision frameworks that promote agricultural economy and development. Figure 2. (on the next page) shows that the PCE-ISys concept is developed from, and buttressed by a series of working suppositions that help form the foundation of the index construct.

Figure 2. Working Suppositions that Support the Rationale for the PCE-ISys Construct
1. The potential for population-level pesticides exposure, and the magnitude of potential exposure (exposure potential) to chemical farming pesticides arise from an agricultural economic system of crop cultivation, food production, trade, and consumption integrated with the broader natural environment and political domain (g-AEES); and that the potential for exposure, and exposure potential do not occur in an environmentally or economically 'isolated,' or 'compartmentalised' manner. In other words, the nature, and magnitude of pesticides total exposure potential is multi-factorial, and an integrated part of the system.
2. There are many social and economic factors that contribute to the potential for human agricultural pesticides exposure, and exposure potential. Four key variables, however, are essential in order to conceptualise, quantify, and rate the potential for such exposure. A) Use of chemicals for the express purpose of crop protection, B) A requisite goal of producing measurable crop outputs for commercial food markets, and livestock productivity, C) Quantifiably discernible land-use allocated for agricultural production, and D) A quantifiably discernible population cohort associated with the given system of economic crop cultivation, food production, consumption, trade and natural environment.
3. Economic, agricultural, and land-use policy decisions (characteristic of agroeconomic environmental systems) are governance variables that affect the potential for population-level pesticides exposure, and exposure potential.
4. Population-based potential for pesticides exposure, and exposure potential occurs from collective (multi-aggregated) pathways, i.e., the summation of potential exposures from dietary intake of food products, drinking water, occupational, and non-occupational inhalation, and dermal routes.
5. Physico-chemical properties of pesticides, and environmental variability and uncertainty are inherently associated with the nature and degree of population-based potential for exposure, and exposure potential.
6. The main source(s) for the potential for population-based pesticides exposure, and exposure potential arise from aggregate agricultural and economic policy decisions from within a population cohort's own country where pesticides are used as inputs for agricultural production.
7. Population-based potential for pesticides exposure, and the magnitude of potential exposure (and risk) are continuously 'shifted' vis-à-vis food commodities consumed, and traded at local, regional, national, and international levels. Thus, the 'distribution' of exposure and risk potential across populations are constantly shifted from one geographical space to another, and that the net 'influx-efflux' of total exposure potential is in a state of variable commercial and ecological 'equilibrium.' This assumption is supported by the measurable ubiquity of pesticides in food commodities, and the natural environment (on a global scale).
8. The existence or absence of, and/or the degree of robustness in health-based regulatory policy (including, compliance and enforcement) impact the extent to which the potential for pesticides exposure, and exposure potential can occur.
9. Agricultural pesticides usage, including intensity of use, and tonnage are not the only variables that contribute to population-based exposure potential, but [usage] *is* the primary agroeconomic systems-based input necessary for human exposure to occur, and for total exposure potential to be observed and evaluated.
10. The Precautionary Principle – Chemical farming pesticides are inherently hazardous to all biological organisms, albeit to varying degrees. Thus, the PCE-ISys exposure indicator and indicator ratio outputs that estimate, and index the potential for exposure and daily exposure potential per person, respectively assumes that lower total (pesticides) exposure potential (by population) is always more favourable compared with higher total exposure potential. Thus, in crafting effective health-protective environmental policy the concept of 'total exposure potential' should be prioritised in developing strategies for reducing pesticides-related health risk, in lieu of a focus on chemical hazard potential and risk.
11. Given the basis for Supposition 10, to gauge risk potential, or to 'hazard-weight' population-based pesticides exposure potential requires access to reliable and accurate empirical, and 'house-keeping' data and information about the approved/registered pesticides allocation profile (by country), and its respective hazard profile.

The eleven working suppositions help illuminate how a 'generalisable' system of agricultural economy manifests the reality of pesticides usage, total exposure potential, and its likely public health implications.

2.2 Uses of PCE-ISys

The PCE-ISys evaluation scheme serves three main functions. First, the system is designed to quantify as a 'weighted' scoring metric the potential for pesticides exposure, and the magnitude of potential exposure at the population level. Next, the construct generates ranking 'profiles' based on two types of index scores ('weighted' and 'unweighted'), and a time series-averaged ranking based on the estimated mean 'weighted' index score (by country). Lastly, PCE-ISys indexes a composite metre of 'weighted' index scores that reflect a global measure of pesticides total exposure potential for all country observation(s); an additional methods-driven approach employs the use of analysis 'factors' to evaluate the annual status and trend of worldwide pesticides total exposure potential.

2.3 Index Scoring Methodology

PCE-ISys is defined by the capacity to evaluate the total exposure potential of agricultural pesticides, that finds its source from industrialised systems of agricultural economy, the key inputs of which include, total estimated land-use for agricultural production, total estimated output from crop seeding and cultivation, and average total annual pesticides-use all in relation to the total population cohort for a given country (g-AEES); therefore making PCE-ISys an evaluation scheme built on macro indicators. As such, the purpose and scope of PCE-ISys as a decision-support tool focuses on total exposure potential in the context of **collective** governance and farm-level decisions, as opposed to individual policy directives such as targeted crop, or pesticides subsidisation, or agricultural tax policy that incentivises, or limits specific farming methods and/or practices.

2.3.1 Methods-Driven Requirements for PCE-ISys Indexing

Indicators that characterise complex systems (such as g-AEES) are fraught with variability, uncertainty, and randomness arising from a host of factors ranging from environmental condition(s) to policy decision-making processes; in turn, leading to challenges in how health and environment outcomes stemming from those system(s) may be interpreted. PCE-ISys is an evaluation scheme that is both data-driven and stochastic. Therefore, interpretative applicability of its indexing results rely on three key elements,

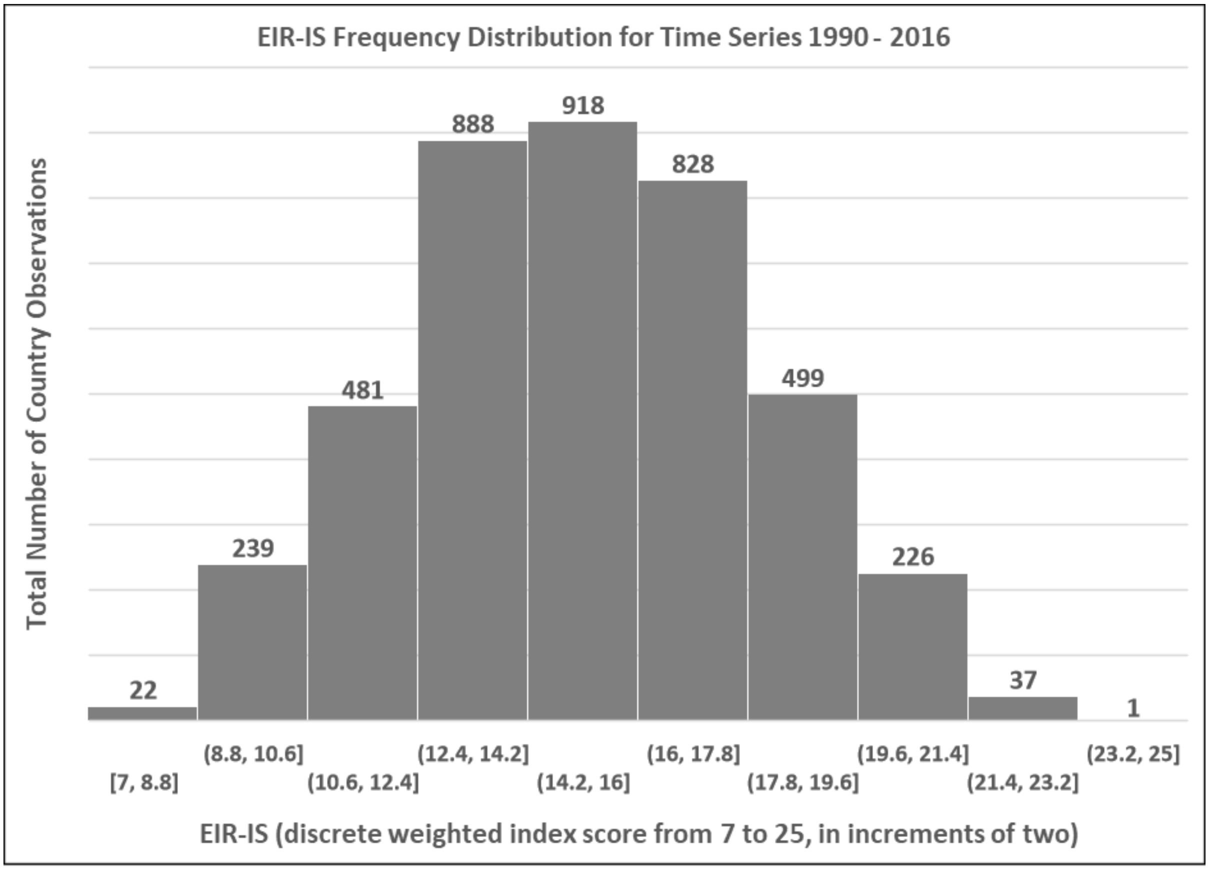
- First, evaluation dataset(s) of adequate sample size. Cochran's Formula for estimating sample size (modified for 'smaller' populations) at 95% confidence was used to provide an idea of the minimum required sample size of nations for the project study (Bartlett II, et al., 2001; Pourhoseingholi et al., 2013),

$$n_o = Z^2pq/e^2 \rightarrow n = \frac{n_o}{1 + (n_o - 1)/N}$$

with ‘p’ (the proportion of the population with the defining attribute) characterised by crop production (by country), where p = 0.91892

- Second is data transformation of g-AEES indicator(s) from continuous variable to discrete value to allow for ‘country-to-country’ comparability, and global trend analysis of pesticides total exposure potential on a relative basis , and
- Lastly, a gaussian distribution requirement for indexing score(s) to allow for valid statistical inference in supporting the foundational elements of the PCE-ISys design construct, i.e., g-AEES, with the model’s response variable output, i.e., EIR-IS. Figure 3. shows a histogram of pesticides total exposure potential scores for all country observations from 1990 - 2016.

Figure 3. Frequency Distribution of Pesticides Total Exposure Potential (EIR-IS), by Country Observation for Time Series 1990 - 2016



PCE-ISys (population-based) pesticides total exposure potential is expressed as an aggregated relative measure (by country) called the Exposure Indicator Ratio-weighted Index Score, or ‘EIR-IS’ representing the potential for exposure, ‘weighted’ by the average daily magnitude of potential exposure (called ‘exposure potential’) on a per capita basis, the summation of which is expressed as the Exposure Ratio Index, or ‘ERI.’

(Eq. 1) EIR-IS (by country) = PCE-IS (by country) + EIR_{score} (by country)

(Eq. 2) Exposure Ratio Index = $\sum$ $EIR\text{-}IS_{country}$ (by year)

EIR-IS is derived from the sum of two relative indexing measures,

- The Pesticides Consumer-Environmental Index Score (PCE-IS), and
- The Exposure Indicator Ratio Score (EIR_{score})

Both metrics are discrete numeric values that correspond to continuous indicator variables (by country). Where the variable(s) fall within one of three percentile categories (upper 25^{th}, middle 50^{th}, and lower 25^{th}) across the distribution of continuous variables for a given evaluation dataset determines the index/indicator score (Han et al., 2012; Toppr, 2020),

- Upper percentile = $(3(n+1)/4)^{th}$ term
- Median percentile = $((n+1)/2)^{th}$ term
- Lower percentile = $((n+1)/4)^{th}$ term

As shown in Figure 4 each percentile category has a designated value, 1-,3-, or 5. '3' is the value 'coded' to continuous indicator variables that fall within the middle 50^{th} percentile of the distribution range. A coded point score of '1' or '5' corresponds to either the upper or lower 25^{th} percentile, depending on how the respective indicator variable is assumed to behave within g-AEES.

Figure 4. PCE-ISys Three-tiered Percentile-based Coded Point Scheme

Key Parameters	Percentile Category (%)	Coded Points	Comments
Total Annual Pesticides Use Rate (by country); Agricultural pesticides-use is directly related to the potential for human exposure	Upper 25^{th}	5	A higher pesticide use rate is associated with a higher point score within the context of g-AEES
	Middle 50th	3	
	Lower 25th	1	
Annual Crop Production Index (by country); Total annual pesticides-use rate is a fixed average measure; therefore, crop productivity is inversely related to potential pesticides exposure	Upper 25th	1	The higher the crop output the lower the pesticide use distribution per unit crop, and thus the lower the score.
	Middle 50th	3	
	Lower 25th	5	
Annual Estimated Agricultural Land Area (by country); The product of pesticides use intensity and total estimated area of land used for agricultural function serves as a direct indicator for pesticides tonnage	Upper 25th	5	Land-use is a key factor in estimating pesticides tonnage. The more land area used for agriculture the higher the score.
	Middle 50th	3	
	Lower 25th	1	
Total Annual Estimated Population (by country);Population size affects the overall health implications associated with pesticides-use within a given a country	Upper 25th	1	Exposure potential is 'diluted' with increasing population relative to total pesticides tonnage.
	Middle 50th	3	
	Lower 25th	5	

PCE-IS represents the potential for pesticides exposure (by country) for one calendar year. The index score is the sum of the percentile category-based designated value(s) for each g-AEES indicator variable, and has a score range from 4 to 20 in incremental units of two. The higher the PCE index score the greater the potential for pesticides exposure.

(Eq. 3) PCE-IS = Percentile-based score for total annual average pesticides use rate + Percentile-based score for annual Crop Production Index + Percentile-based score for total agricultural land area + Percentile-based score for annual estimated country population

The EIR_{score} represents a discrete relative value for pesticides 'exposure potential.' The score is a numeric 'weighting' factor (when combined) with PCE-IS produces a total exposure potential score (EIR-IS), with an index scale of 5 to 25 (by country). Similar to the PCE-IS scoring methodology, EIR_{score} (by country) is scored based on where the Pesticides Exposure Indicator Ratio ($Pi_{exp}R$) variable falls within the data distribution range of all $Pi_{exp}R$ values for the given evaluation dataset (by year), which is seen in Figure 5.

Figure 5. PCE-ISys Percentile-based Coded Point Scheme for $Pi_{exp}R$			
Key Parameters	**Percentile Category** (%)	**EIR Coded Points**	**Comments**
$Pi_{exp}R$ (by country); a relative measure of daily pesticides exposure potential per capita	Upper 25th	5	EIR_{score} is the numeric relative measure of $Pi_{exp}R$ that is used to 'weight' PCE-IS
	Middle 50th	3	
	Lower 25th	1	

The higher the $Pi_{exp}R$ value across the distribution range, the higher the (percentile category-based) EIR_{score}, and vice versa.

$Pi_{exp}R$ is a unitless continuous variable that represents the relative average measure of daily pesticides exposure potential that is equal to, exceeds, or is below the Pesticides Reference Indicator Ratio ($Pi_{ref}R$) expressed as follows,

$$\text{(Eq. 4) } Pi_{exp}R = Pi_{exp}UC / Pi_{ref}UC$$

where $Pi_{exp}UC$ (the unit-converted Pesticides Exposure Indicator) is a function of the product of the unit-converted pesticides-to-crop productivity ratio (PCPr) and farm land area per capita (FLAC),

$$\text{(Eq. 5) } Pi_{exp} = PCPr \times FLAC \text{ (unit-kg}_{pesticides} \text{ per person / year)}$$

↓

$$\frac{PCPr_{country} \text{ (kg}_{pesticides} \text{ / ha)} \times FLAC_{country} \text{ (ha/person)}}{\text{Annual (1-year)}} = Pi_{exp}$$

[unit conversion]

↓

$$\text{(kg}_{pesticides} \text{ /person-year) (1-year/365 days) (1*}10^6 \text{ mg /1 kg}_{pesticides}) =$$

↓

$$\text{Pesticides Exposure Indicator } (mg_{pesticides} \text{ per person-day}) = Pi_{exp}UC$$

where,

$$\underbrace{\frac{\text{Total (Annual) Pesticides Use Rate (kg/ha)}}{\text{Annual Crop Production Index}}}_{\textbf{Pesticides-to-Crop Productivity Ratio (PCPr)}} \times \underbrace{\frac{\text{Total (Annual) Agricultural Land Area (ha)}}{\text{Annual Estimated Country Population}}}_{\textbf{Farmland Area per capita (FLAC)}}$$

The Pesticides Reference Indicator ($Pi_{ref}UC$) is a unit-converted benchmark level that represents the 95% upper bound limit of the mean (unit-converted) Pesticides Exposure Indicator values for all countries (within a given evaluation dataset) that have annual total average pesticides use rate(s) less than or equal to 0.5 kg/ha.

$$Pi_{ref}UC = 95\% \text{ UCL of } \mu_{Pi_{exp}UC} \text{ (pesticides use rate} \leq 0.5 \text{ kg/ha, 'low')}$$

Use rate reference levels, such as 0.5 kg/ha are adopted as a modified version of the Wachter & Staring guideline protocol cited in the 1990 WHO report, *Public Health Impact of Agricultural Pesticide Use*. The guideline rates patterns of use for agricultural pesticides active ingredient based on the status of economic development (by country), where annual pesticides active ingredient use amounts of 0.5 kg/ha to ≤ 0.1 kg/ha is graded as 'low' while <0.1 kg/ha annual pesticides active ingredient use rate is graded as 'very low.' The derivation for the Pesticides Reference Indicator (**Pi_{ref}**) is the summation of all **Pi_{exp}** values from countries whose average annual pesticides use rate is at, or below 0.5 kg/ha divided by the total number of countries (within the data subset) whose annual pesticides use rates are at or below 0.5 kg/ha. $Pi_{ref}UC$ represents the average daily pesticides exposure potential that is rated as a 'lower appreciable public health concern.'

2.3.2 PCE-ISys Public Health Rating Scheme

The PCE-ISys evaluation model is **not** a tool designed to reflect estimation(s) of risk or impact(s) associated with the use of crop protection chemicals. Instead, [it] is a data-driven construct that produces a relative measure of pesticides-related exposure, so is directly dependent on sample size, and g-AEES parameter values from each respective evaluation dataset. At the same time, the public health rating scheme for the index is rooted in the application of the Precautionary Principle (based on Working Supposition 10) expressed through a generic qualitative rating. The basis for the indexing system's public health-related rating scheme is centred on three basic precepts,

- That chemical pesticides are engineered to produce target organism mortality, but also manifest varying degrees of 'collateral' toxicity to other biological species, including humans.
- That pesticides-related health impact(s) and risk are function(s) of pesticides exposure.
- That pesticides risk reduction through 'integrated' policy and planning measure(s), over the long-term, are best accomplished, and more cost-effective through prevention efforts, as opposed to 'command and control' impact mitigation.

PCE-ISys public health rating categories correspond to pesticides total exposure potential as a function of EIR-IS or PCE-IS percentile scoring distribution(s). Therefore, index scores within the upper 25th percentile are deemed of 'highest' total exposure potential, within the 50th percentile are deemed of 'medium-to-high' total exposure potential, and within the lower 25th percentile are deemed of 'lower' total exposure potential. Figure 6. illustrates that the public health classification measure for the indexing system is a generic, qualitative expression termed 'Appreciable public health concern.' The rating is, however, a component of the ERI Proportional Estimation methodology, so is directly dependent on the sample size, and parameter values for each respective evaluation dataset.

Figure 6. Public Health Rating Classification Scheme

Response Output	**Percentile Category** (%)	**Total Exposure Potential Rating**	**Public Health Rating**	**Comments**
EIR-IS or **PCE-IS** **(**by country)	Upper 25th	Highest	Highest Appreciable Public Health Concern	EIR-IS or PCE-IS (by country) are categorised into Three-tiered percentiles based on the stochastic distribution for each respective evaluation dataset
	Middle 50th	Medium to High	Appreciable Public Health Concern	
	Lower 25th	Lower	Lower Appreciable Public Health Concern	

The scoring classifications across each data distribution range are ordered according to percentile range: Upper 25th%ile = Highest Appreciable, Median = Appreciable, and Lower 25th%ile = Lower Appreciable. Based on the index score distribution(s), the cut-off levels for each respective percentile range for this project study was as follows,

- EIR-IS ≥ 17 (Upper 25th), EIR-IS = 15 (Middle 50th), EIR-IS ≤ 13 (Lower 25th)
- PCE-IS ≥ 14 (Upper 25th), PCE-IS = 12 (Middle 50th), PCE-IS ≤ 10 (Lower 25th)

2.3.3 Indexing Global Pesticides Total Exposure Potential

As shown in equation 2 (section 2.3.1), the Exposure Ratio Index (ERI) is a composite measure of total exposure potential for the aggregate number of country observations in each evaluation dataset (by year). Thus, ERI serves as a 'global' index for aggregated total pesticides exposure potential arising from collective 'generalisable' systems of agricultural economy and environment (by year). Figure 7. summarises the basic 'Analysis Factors' used in conducting the Exposure Ratio Index Analysis (ERI Analysis). ERI Analysis offers a data-driven interpretation of worldwide total exposure potential (by year).

Figure 7. PCE-ISys Exposure Ratio Index Basic Analysis Factors

Analysis Factor	Description
Exposure Ratio Index (ERI)	The annual global pesticides total exposure potential, where total exposure potential is the yearly 'per capita' potential for agricultural pesticides exposure combined with the 'weighted' magnitude of potential exposure (by country). The term 'global' means the sample of countries included in each evaluation dataset for the time series. The ERI value is stochastic and variable by country and time. It is the sum total of the individual EIR-IS for each country within each evaluation dataset.
Max Exposure Ratio Index (ERI_{max})	The annual global pesticides maximum total exposure potential, where maximum total exposure is the highest possible total (pesticides) exposure potential worldwide for a one-year period (by country).
Min Exposure Ratio Index (ERI_{min})	The annual global pesticides minimum total exposure potential, where minimum total exposure is the lowest possible total (pesticides) exposure potential worldwide for a one-year period.
Exposure Ratio Index Percent (ERIP)	ERIP is ERI as a percentage of ERI_{max}, $\frac{ERI}{ERI_{max}} \times 100$ and provides a relative measure of worldwide pesticides total exposure potential (ERI) in relation to the highest possible worldwide total exposure potential (ERI_{max}) over one calendar year.
Exposure Ratio Index Quotient (ERIQ)	The ratio of the Exposure Ratio Index to the Min Exposure Ratio Index. $\frac{ERI}{ERI_{min}}$ ERIQ is a continuous variable from 1 - 5 that represents the relative magnitude of worldwide pesticides total exposure potential in relation to the lowest possible worldwide total exposure potential (ERI_{min}) for a given calendar year. It is the measure of how 'close' or how 'far off' the Exposure Ratio Index is from the lowest possible global pesticides total exposure potential i.e., ERI_{min}, and is the base metric used to interpret the distance at, or above the level of 'Lower Appreciable public health concern.

'Derivative' Analysis Factors help to provide additional, more in-depth insight into the overall ERI Analysis, and includes,

- The Margin of Exposure Ratio Index is the percent difference between the global percent maximum total exposure potential (ERIP = 100%), and the estimated global percent total exposure potential (ERIP) for a given evaluation dataset,

  (Eq. 6) Margin of Exposure Ratio Index = 100% - estimated ERIP (by year)

  Eighty percent is the highest possible Margin of Exposure Ratio Index, and indicates a worldwide margin of total exposure potential in line with an ERIP of 20%, the level that elicits a rating of 'Lower Appreciable public health concern.'

- The Exposure Ratio Index Threshold Difference Ratio (ERI-TD Ratio) is a continuous variable from 0 to 4. It is the relative degree to which the Exposure Ratio Index Threshold Difference (ERI-TD) lies between 80% to 0%, the former being equivalent to an ERIP of 100% (Margin of Exposure Ratio Index = 0%), and the latter having equivalency to the Percent Threshold Minimum Exposure Ratio Index, respectively. They are calculated using the following methods,

  (Eq. 7) ERI-TD = ERIP - Percent Threshold Minimum Exposure Ratio Index

  (Eq. 8) ERI-TD Ratio = $\frac{\text{Exposure Ratio Index Threshold Difference}}{\text{Percent Threshold Minimum Exposure Ratio Index}}$

Table 1. highlights key derivative analysis factors, and possible ERI Analysis outcomes.

Table 1. ERI Analysis Table - Analysis Factors used in Exposure Ratio Index Analysis

Exposure Ratio Index Percent (%)	Margin of Exposure Ratio Index (%)	Percent Threshold Minimum Exposure Ratio Index (%)	Exposure Ratio Index Threshold Difference (%)	ERI-TD Ratio
100	0	20	80	4
90	10	20	70	3.5
80	20	20	60	3
70	30	20	50	2.5
60	40	20	40	2
50	50	20	30	1.5
40	60	20	20	1
30	70	20	10	0.5
20	80	20	0	0

The second component of ERI Analysis, the ERI Proportional Estimation involves calculating the distribution of EIR-IS or PCE-IS observations (by country, by year) relative to its respective Exposure Ratio Index (by year) across three percentile categories (upper 25th, middle 50th, and lower 25^{th}). For analysis purposes the metric reflects the number of EIR-IS (or PCE-IS) country observations (by year) that fall into two index rating categories,

(1) highest and medium-to-high total exposure potential = Highest Appreciable and Appreciable public health concern, and (2) lower total exposure potential = Lower Appreciable public health concern.

While methodological rigour characterises PCE-ISys, its indexing outputs are reasonably transparent making them likely to be broadly understood by decision-makers, as well as civil society. Transparency and ease of use are key elements in the universal applicability of indexing systems, particularly when examining the public health implications of agricultural and economic policy decision outcomes.

2.4 Data Methodology

2.4.1 Data Sources

Data that reflect the model input variables for the PCE-ISys model construct are available as open access from UN FAO and World Bank websites. Pesticides use data was accessed from the FAO website, http://www.fao.org/faostat/en/?#data/RP, and separately downloaded in bulk as Excel files categorised by world regions Africa, Americas, Asia, Europe, and Oceania. Data for the rest of the model input variables were accessed at the following World Bank websites by doing total bulk data downloads as '.csv' files then saved as Excel '.xlsx' files, 1) for Crop Production Index, https://data.worldbank.org/indicator/AG.PRD.CROP.XD, 2) for annual total population estimates by country, https://data.worldbank.org/indicator/SP.POP.TOTL, 3) for annual total land area by country, https://data.worldbank.org/indicator/AG.LND.TOTL.K2, and 4) for annual percent land area for agriculture, https://data.worldbank.org/indicator/AG.LND.AGRI.ZS. Data from the World Bank site representing the model input variables were extracted from the original downloaded spreadsheets, and collated into columns in new worksheets that included data from 268 countries, world regions, and other world development classification categories.

2.4.2 Organising the Data, and Data Testing the Model

Data collected from World Bank and FAO websites were organised and managed using Microsoft Office Excel version 16.43. The PCE-ISys working model was developed using Excel because of the ease of use of the application's mathematical functions to generate the indicator, and index outputs by country, and by year.

A 'source' dataset worksheet was used to consolidate, and organise all raw, and processed data for the project. The basic steps for the worksheet data consolidation and organising process were as follows, 1) all g-AEES (indicator variable) data were entered into the source worksheet. This included all 268 countries, world regions, and other world development classification categories, 2) all categories (except for individual countries) were culled from the source worksheet; use of Cochran's Formula at 95% confidence (section 2.3.1) estimated the minimum required sample size (n) per evaluation dataset for the project study to be (at least) 76 countries, 3) the remaining individual countries were further screened to include only those with total average annual pesticides-use rate data ($157 \geq n \geq 133$). Consumption rate data (by country) were available from years 1990 – 2016 (the evaluation 'time series' for the project study). 2016 was the terminal year of the time series because (at the time of data collection) there was no crop production index data beyond that year. 4) g-AEES indicator variable, total land area was unit-converted from square kilometres to hectares in order to comport with the unit expression used in the PCE-ISys model, then total agricultural land area (by year) was calculated by total land area (by country) as a percent of land area allocated for agriculture (by country), 5) eight additional columns were added to the source worksheet dataset. The four initial data columns included the land area unit conversion, then calculation of total agricultural land, and PCPr and FLAC output calculations, respectively. 6) The final four additional columns included, calculation and unit conversion of Pi_{exp} (kg/person-year) to $Pi_{exp}UC$ (mg/person-day), inclusion of $Pi_{ref}UC$ values, calculation of $Pi_{exp}R$ ($Pi_{exp}UC/Pi_{ref}UC$), and then scale-adjusted by a factor of 10 (Adjusted-$Pi_{exp}R$ = $Pi_{exp}UC/Pi_{ref}UC \times 10$).

Eighteen auxiliary columns were added to the source worksheet, three columns for each g-AEES indicator variable and EIR_{score} percentile range i.e., the Excel '= percentile' function for upper 25^{th} ('75^{th}'), 50^{th}, and lower 25^{th}; and the last three auxiliary columns for index scoring PCE-IS, totalling EIR_{score}, and index scoring EIR-IS. All indicator variable data (by country) for twenty-seven evaluation datasets in the project study were indexed to generate PCE-IS and EIR-IS for all country observations for the time series.

2.5 PCE-ISys Model – Correlation and Variance

2.5.1 Multivariate Test for EIR-IS and g-AEES

A regression analysis was conducted to determine the strength of correlation between the PCE-ISys weighted index score (response variable), and its respective g-AEES indicator (input) variables that define the systems-based model construct. Neither analysis of output trend, nor model predictiveness was the focus of the regression exercise. Therefore, nested linear models were not utilised. Instead, the input variables, and its respective index output, i.e., EIR-IS were averaged for each year of the time series (by country), and a standard multivariate analysis was employed. Figure 8. shows the EIR-IS linear response output in relation to the four key indicator variables that characterise the g-AEES-based model,

Figure 8. PCE-ISys Correlation and Variance for Time Series-Average EIR-IS as a Function of g-AEES (1990 – 2016)

Regression Variables	Pearson Coefficient	Multivariate R-Square	F-Test Significance Level	Sample Size
EIR-IS (average weighted index score) 1990-2016	0.657789111	0.417757212	6.6154E-18	157
	p-value			
Intercept	9.68459E-28			
Average Annual Pesticides Use Rate 1990-2016	1.47004E-18			
Average Annual Crop Production Index 1990-2016	3.77942E-05			
Average Total Annual Agricultural Land Area (ha) 1990-2016	0.017217896			
Average Annual Estimated Population (by country) 1990-2016	0.078810616			

The regression model demonstrated reasonably strong association between average EIR-IS and average pesticides consumption, average Crop Production Index, average agricultural land area, and average estimated country population, with r=0.657789, and multivariate R^2 indicating that the g-AEES model system explained nearly 42% of the variance in EIR-IS.

2.5.2 Multivariate Test for EIR-IS and Exposure Potential

A second regression test was conducted to examine the strength of correlation between average EIR-IS, and indicator variables used to derive $Pi_{exp}UC$ 'exposure potential,' i.e., the estimated daily magnitude of potential pesticides exposure per capita. Figure 9. shows the EIR-IS linear response output in relation to the two indicator variables used to determine exposure potential, i.e., PCPr and FLAC,

Figure 9. PCE-ISys Correlation and Variance for Time Series-Average EIR-IS as a Function of $Pi_{exp}UC$ (1990-2016)

Regression Variables	Pearson Coefficient	Multivariate R-Square	F-Test Significance Level	Sample Size
EIR-IS (average weighted index score) 1990-2016	0.699048231	0.482027759	3.71621E-23	157
	p-value			
Intercept	1.20E-106			
Pesticides-to-Crop Productivity Ratio (average PCPr) 1990-2016	1.70E-20			
Average Total Farm Land Area per Capita (average FLAC) 1990-2016	8.16E-09			

The multivariate output results for EIR-IS and pesticides exposure potential similarly demonstrated a relatively strong correlation between average (pesticides) total exposure potential and average daily magnitude of potential exposure (per person) with r=0.699048. Variance in EIR-IS as a function of 'exposure potential' was R^2=0.48 indicating that nearly half the change in EIR-IS output(s) were explained by pesticides use per unit of crop productivity, and agricultural land area per capita (a surrogate indicator for pesticides tonnage).

All indicator variables for both models were statistically significant, except for 'Average Annual Estimated Country Population,' which was marginally non-statistically significant (p-value = 0.078810616); though this occurrence was not altogether unexpected given the complex and dynamic nature of human-to-environment interaction. The fact that FLAC turned out as a statistically significant, linearly correlated variable relative to EIR-IS points to country population as a relevant indicator variable (in the context of pesticides tonnage) for interpreting pesticides total exposure potential, but at the same time difficult to elucidate through semi-quantitative indexing; and likely requires a considerably more complex computational modelling exercise.

3 PCE-ISys TESTING APPLICATION(S)

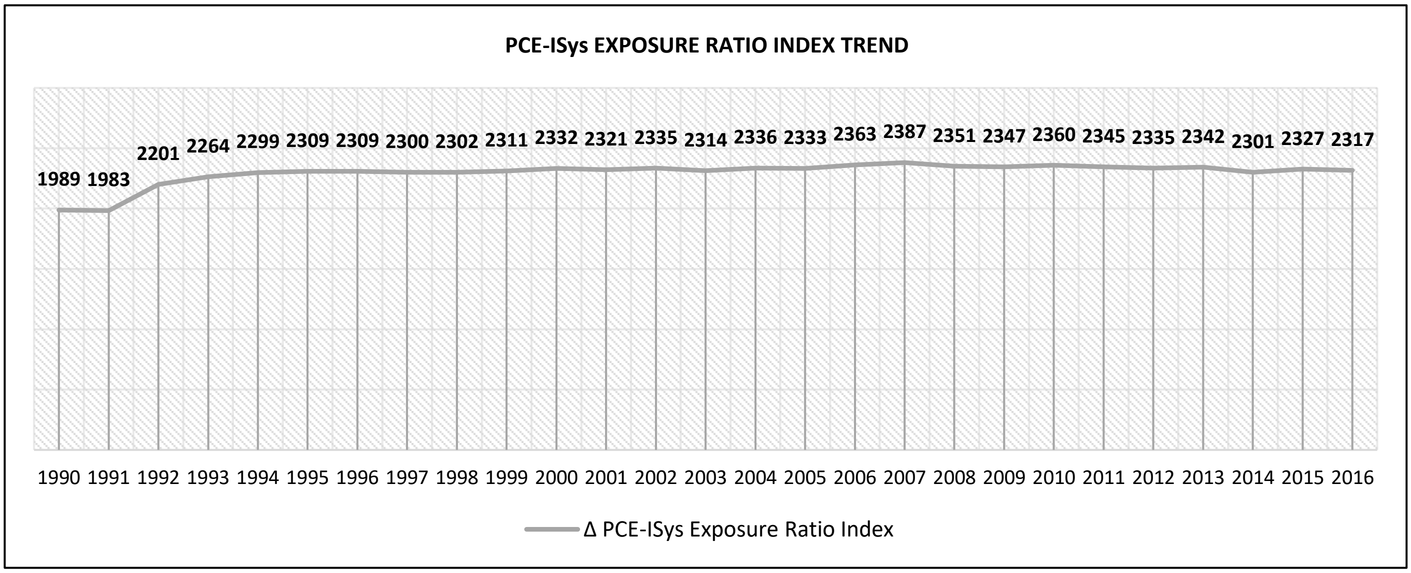
3.1 Global Pesticides Total Exposure Potential

The applicability of PCE-ISys in explaining the potential public health related implications arising from highly variable systems of policy, economy, and environment centre on the 'behaviour' and interpretability of such systems in the aggregate. That is, the index score and analysis factor outputs for one country are stochastically reliant on, and directly comparable among all countries within each respective evaluation dataset under an assumption of g-AEES.

3.1.1 Exposure Ratio Index and ERI Analysis (1990 – 2016)

The PCE-ISys Exposure Ratio Index for any given time series provides a way in which to numerically visualise 1) the yearly worldwide pesticides total exposure potential, and 2) the trend in global total exposure potential over any given time series. Figure 10. captures the pattern of change in total exposure potential worldwide from 1990 to 2016 based on the sum total of each country's EIR-IS (by year).

Figure 10. The Global Trend in PCE-ISys Exposure Ratio Index (1990-2016)



The observed trend in ERI from 1990 to 2016 (26-year span) appears visually static. Yet, total year-over-year Δ Exposure Ratio Index for the times series demonstrated a +16% change, or a net increase of 334 index points. Analysis factor ERI outcomes are implicit in the ERI trend visualisation seen in the Figure 11., and supported by Table 2.

Figure 11. The ERI_{min}, ERI, and ERI_{max} Trend Relationship (by year) for Time Series 1990-2016

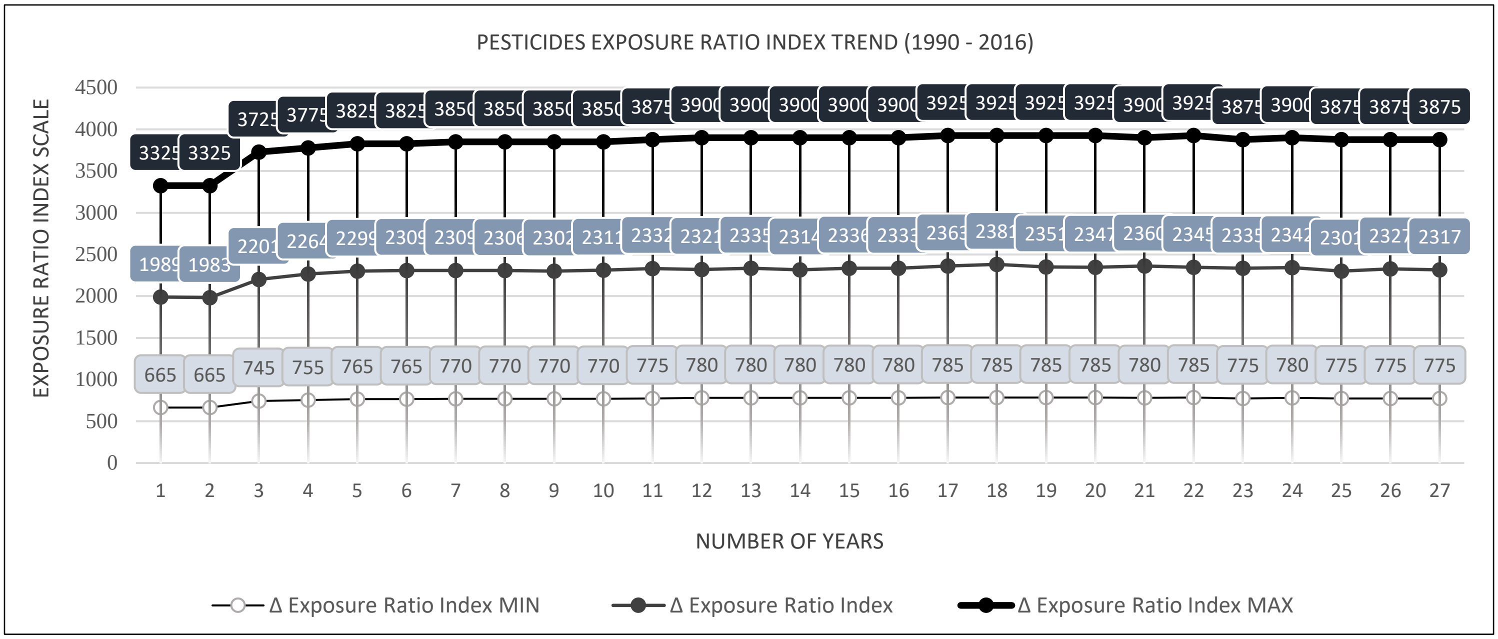


Table 2. Results of the ERI Analysis 27-year time series (1990 – 2016)

Geographic Space	Year	PCE-ISys Exposure Ratio Index	ERI_{max}	ERIP (%)	Margin of Exposure Ratio Index (%)	ERI-TD Ratio	ERI_{min}	ERIQ
Global	1990	1989	3325	59.82	40.18	1.99	665	2.99
Global	1991	1983	3325	59.64	40.36	1.98	665	2.98
Global	1992	2201	3725	59.09	40.91	1.95	745	2.95
Global	1993	2264	3775	59.97	40.03	2.00	755	3.00
Global	1994	2299	3825	60.11	39.89	2.01	765	3.01
Global	1995	2309	3825	60.37	39.63	2.02	765	3.02
Global	1996	2309	3850	59.97	40.03	2.00	770	3.00
Global	1997	2306	3850	59.90	40.10	2.01	770	3.00
Global	1998	2302	3850	59.79	40.21	1.99	770	2.99
Global	1999	2311	3850	60.03	39.97	2.00	770	3.00
Global	2000	2332	3875	60.18	39.82	2.01	775	3.01
Global	2001	2321	3900	59.51	40.49	1.98	780	2.98
Global	2002	2335	3900	59.87	40.13	1.99	780	2.99
Global	2003	2314	3900	59.33	40.67	1.97	780	2.97
Global	2004	2336	3900	59.90	40.1	2.00	780	3.00
Global	2005	2333	3900	59.82	40.18	1.99	780	3.01
Global	2006	2363	3925	60.20	39.80	2.01	785	3.03
Global	2007	2387	3925	60.82	40.82	2.04	785	3.04
Global	2008	2351	3925	59.90	40.1	2.00	785	2.99
Global	2009	2347	3925	59.80	40.2	1.99	785	3.03
Global	2010	2360	3900	60.51	39.49	2.03	780	2.99
Global	2011	2345	3925	59.75	40.25	2.01	785	3.01
Global	2012	2335	3875	60.26	39.74	2.01	775	3.00
Global	2013	2342	3900	60.05	39.95	2.00	780	2.97
Global	2014	2301	3875	59.38	40.62	1.97	775	3.00
Global	2015	2327	3875	60.05	39.95	2.00	775	2.99
Global	2016	2317	3875	59.79	40.21	1.99	775	3.00

The results of the global pesticides ERI Analysis are summed up as follows,

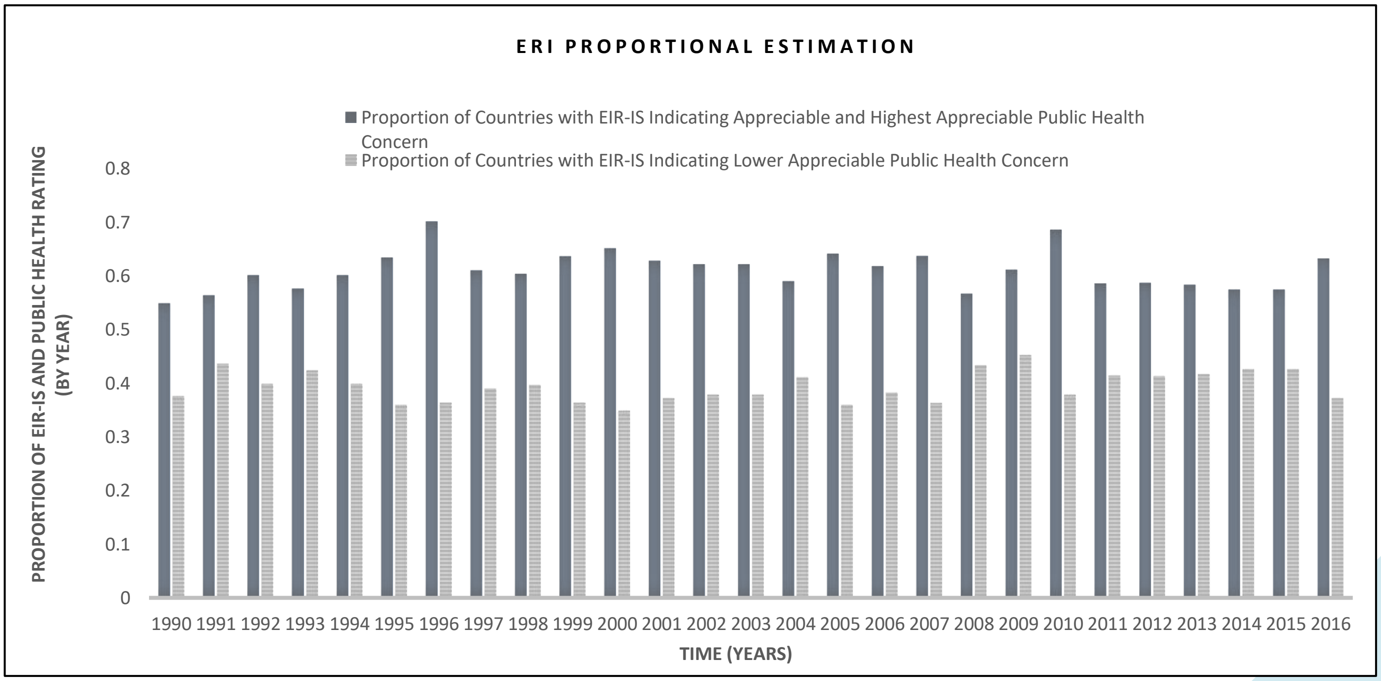
- Year-over-year average ‘drop line’ distance(s) between Δ Exposure Ratio Index MAX and Δ Exposure Ratio Index for the time series indicate the Margin of Exposure Ratio Index to be fractionally over 40%, while
- Year-over-year average ‘drop line’ distance(s) between Δ Exposure Ratio Index and Δ Exposure Ratio Index MIN, i.e., ERIQ was fractionally below 3
- Using ERI Analysis methodology from section 2.3.3, i.e., year-over-year average estimated ERIP (59.92%) and Percent Minimum Threshold Exposure Ratio Index (constant), the average ERI-TD Ratio for the 26-year span was calculated at 1.998

The ERI Analysis results from this project study point to a tangible level of public health concern regarding worldwide pesticides total exposure potential. Along with a sixteen percent increase in ERI for the 27-year time series, ERIQ averaged over the 26-year span demonstrated that year-over-year ERI exceeded ERI_{min} by 300%. Moreover, an ERI-TD Ratio half the distance quotient to maximum global pesticides total exposure potential, and a year-over-year average Margin of Exposure Ratio Index at 50% maximum all constitute further pesticides-related public health concern on a global level.

3.1.2 ERI Proportional Estimation (1990 – 2016)

As a component of ERI Analysis, the ERI Proportional Estimation provided a measure of the number of country observations with EIR-IS ≥ 15 relative to those observations with EIR-IS ≤ 13. Figure 12. shows the of proportion of countries with Appreciable and Highest Appreciable public health concern compared to the proportion with Lower Appreciable public health concern (by year).

Figure 12. ERI Proportional Estimation by year and time series trend for 1990 – 2016

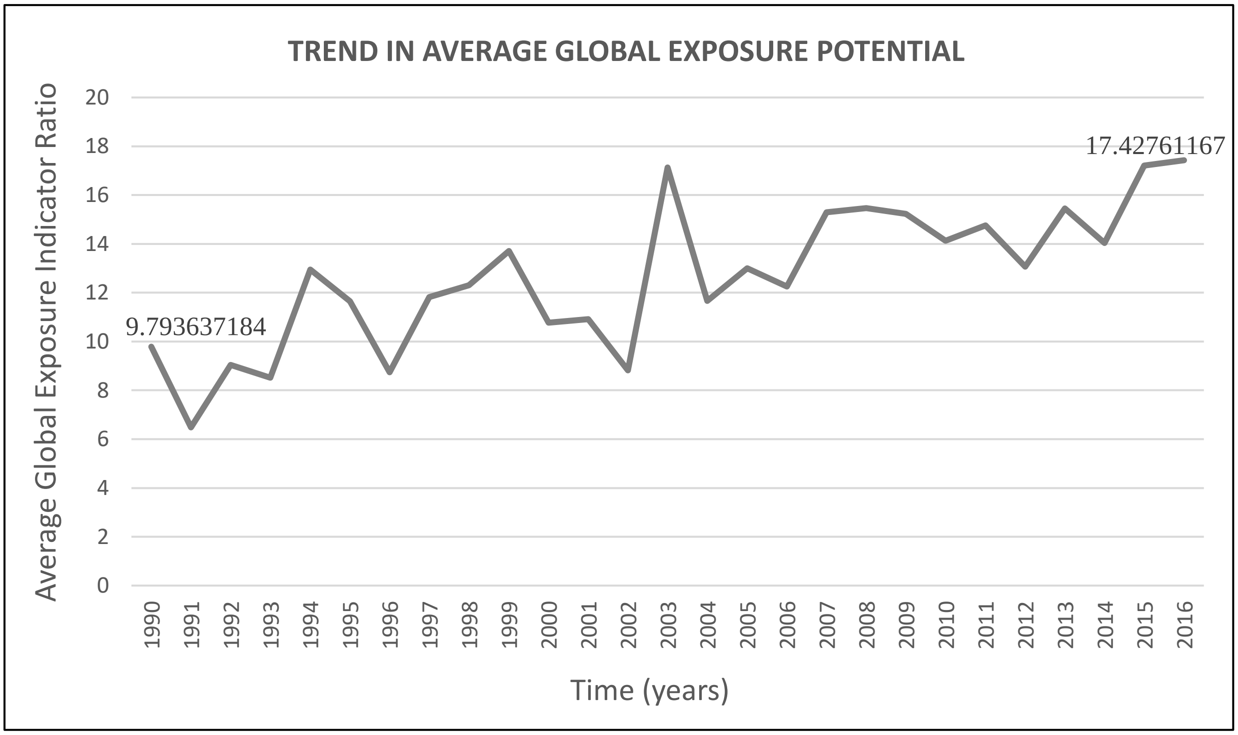


The number of countries rated with Appreciable public health concern (medium-to-high total exposure potential, 17 > EIR-IS > 13) and Highest Appreciable public health concern (highest total exposure potential, EIR-IS ≥ 17) outpaced the number of countries with Lower Appreciable public health concern (lower total exposure potential, EIR-IS ≤ 13) by a factor of 1.633 to 1. For the 26-year span, on average, 63% of countries were rated as having Appreciable or Highest Appreciable public health concern regarding total exposure potential with nearly two-thirds (64%) of those countries having received a weighted index score (EIR-IS) ≥ 17. Based on the PCE-ISys rationale and construct the year-over-year total index proportional estimate demonstrated that the majority of countries worldwide between 1990 to 2016 suffered levels of pesticides total exposure potential that exceeded what would be considered acceptable from a public health standpoint.

3.2 Global Pesticides Exposure Potential

Although not a formal component of the ERI Analysis, presenting and discussing the worldwide 26-year change in pesticides relative exposure potential is a worthwhile exercise in the context of the Exposure Ratio Index trend. As discussed earlier in the paper, pesticides exposure potential is defined as the magnitude of potential exposure (by country, by year), and $Pi_{exp}R$ is the unitless relative measure representing this metric. Figure 13. illustrates the 26-year trend in average worldwide (relative) magnitude of potential exposure (by year).

Figure 13. Global Trend in the Average Daily Magnitude of Potential Pesticides Exposure



The average global year-over-year $Pi_{exp}R$ exhibited a high degree of variability. The trend outcome, however, was distinct. There was a clear increase in the average global magnitude of potential pesticides exposure over the 26-year span. At the start of the time series average global relative exposure potential was estimated at just under 9.8 indicating that on average, global exposure potential was already considerably high, i.e., nearly 10-times the $Pi_{ref}R$. By 2016, the average global $Pi_{exp}R$ increased by 78% to 17.43, meaning that the average magnitude of potential exposure (Adj-$Pi_{exp}R$) for populations worldwide increased to nearly 17.5x the $Pi_{ref}R$. The average upward trend in global $Pi_{exp}R$ along with the 16% increase in ERI during the same period indicates that worldwide use, and total exposure potential of chemical farming pesticides remain an on-going concern for health and environment.

3.3 Pesticides Total Exposure Potential Ranking Profiles

A key function of PCE-ISys in terms of policy decision-support applicability (by country) is the capacity to evaluate the potential for pesticides exposure, the magnitude of potential exposure (exposure potential), and total exposure potential by way of ranking profiles for a given country. The year-over-year ranking profiles for each country include, EIR-IS and PCE-IS outputs, and relative numeric rankings based on each country's corresponding Adj-$Pi_{exp}R$. Due to the high number of ranking profiles, and their associated g-AEES parameter values (8,278 total country observations), all indexing results, and g-AEES data have been made available as open access at www.threepercentearth.org (with proper referencing to Three Percent Earth Foundation).

3.3.1 Sample Ranking Profile from the 2016 Evaluation Dataset

A sample selection from the 2016 PCE-ISys ranking profile in Figure 14. shows the top 10 nations with the highest and lowest potential for pesticides exposure, and highest and lowest magnitude of potential exposure.

Figure 14. 2016 Country Ranking Profile Sample :
Top 10 Nations with Highest and Lowest Appreciable Public Health Concern

COUNTRY	YEAR	EIR-IS (weighted index score)	PCE-IS (index score)	Pesticides Exposure Indicator Ratio ($Pi_{exp}R$)	2016 Scale Adjusted-$Pi_{exp}R$ RANK
St. Lucia	2016	21	16	290.6939387	1
Malaysia	2016	19	14	289.2590196	2
Ecuador	2016	21	16	283.4271558	3
Costa Rica	2016	19	14	187.191331	4
Belize	2016	23	18	171.185618	5
Trinidad and Tobago	2016	21	16	114.093936	6
Guatemala	2016	19	14	77.95695761	7
Fiji	2016	21	16	71.83512271	8
Portugal	2016	19	14	64.15605845	9
Spain	2016	17	12	58.25914692	10

Mongolia	2016	7	6	0.00984	146
Angola	2016	9	8	0.00832	147
Botswana	2016	11	10	0.00759	148
Chad	2016	9	8	0	149
Congo, Rep.	2016	11	10	0	150
Comoros	2016	13	12	0	150
Lao PDR	2016	9	8	0	150
Niger	2016	9	8	0	150
Pakistan	2016	11	10	0	150
Tanzania	2016	9	8	0	150

This sample of the 2016 ranking profile helps validate the simplicity of use and interpretation of information from PCE-ISys for purposes of policy decision-support. All countries within the top 10 ranking profile selection rated as having Highest Appreciable public health concern, scored at minimum, pesticides total exposure potential EIR-IS ≥ 17 with an average EIR-IS = 20. Half the countries ranked among the 2016 top 10 scored 21 or higher. Next, those same countries among the top 10 also scored 'unweighted' indices PCE-IS ≥ 14 (the minimum 'cut-off' score level deemed of highest potential for exposure), except for Spain that scored within the middle 50^{th} percentile. Otherwise, half the country observations among this group scored PCE-IS ≥ 16, and nine out of 10 scored 14, or higher. At the other end of the ranking profile spectrum, the average EIR-IS was 9.7 among countries with lower total exposure potential. Tanzania's EIR-IS and PCE-IS were 9 and 8, respectively while the country's scale adjusted $Pi_{exp}R$ Rank was 150 with a $Pi_{exp}R$ of effectively '0.' Seven of 10 countries ranked as having lower total exposure potential had $Pi_{exp}R$ values of '0.' In terms of either the potential for pesticides exposure, or exposure potential absolute '0' is an unlikely scenario. Instead, the PCE-ISys evaluation scheme assumes that '0' represents (at least) some fractional level of potential exposure approaching zero.

3.3.2 Average EIR-IS$_{country}$ Ranking Profile (1990 – 2016)

In addition to year-over-year index scores for total potential pesticides exposure, PCE-ISys can be used to construct a time-averaged EIR-IS ranking platform (by country). Figure 15. on page 23 illustrates the average EIR-IS ranking schedule for the 1990 – 2016 time series.

Figure 15. Time Series-Averaged Exposure Indicator Ratio-Weighted Index Score and Rank (1990 – 2016)

COUNTRY	AVERAGE EIR-IS	WORLD RANK	COUNTRY	AVERAGE EIR-IS	WORLD RANK	COUNTRY	AVERAGE EIR-IS	WORLD RANK	COUNTRY	AVERAGE EIR-IS	WORLD RANK
Belize	21.37037037	1	Malta	17	42	Gambia, The	14.92592593	81	Bhutan	12.85185185	117
Malaysia	21.22222222	2	Nicaragua	17	42	Bulgaria	14.77777778	82	Timor-Leste	12.85185185	117
Slovenia	20.84	3	El Salvador	16.92592593	44	Qatar	14.77777778	82	Kenya	12.77777778	119
Guatemala	20.33333333	4	Philippines	16.92592593	44	Zimbabwe	14.77777778	82	Estonia	12.76	120
Cyprus	20.18518519	5	Paraguay	16.85185185	46	Peru	14.7037037	85	INDONESIA	12.7037037	121
Ecuador	19.96296296	6	CANADA	16.77777778	47	Venezuela, RB	14.7037037	85	Ireland	12.7037037	121
Portugal	19.88888889	7	Spain	16.77777778	47	Albania	14.62962963	87	Myanmar	12.55555556	123
West Bank and Gaza	19.7826087	8	North Macedonia	16.6	49	Algeria	14.62962963	87	Togo	12.55555556	123
ITALY	19.44444444	9	Netherlands	16.55555556	50	Bahrain	14.62962963	87	Kazakhstan	12.52	125
Maldives	19.41666667	10	Sri Lanka	16.48148148	51	RUSSIAN FEDERATION	14.6	90	Bangladesh	12.48148148	126
Greece	19.14814815	11	Uruguay	16.40740741	52	Ukraine	14.6	90	Hong Kong SAR, China	12.33333333	127
Israel	19.14814815	11	Thailand	16.33333333	53	JAPAN	14.55555556	92	Pakistan	12.25925926	128
Colombia	19.07407407	13	Tunisia	16.33333333	53	St. Kitts and Nevis	14.55555556	92	Madagascar	12.18518519	129
Costa Rica	19	14	Oman	16.11111111	55	Guinea-Bissau	14.48148148	94	Poland	12.18518519	129
Chile	18.85185185	15	Luxembourg	15.94117647	56	Czech Republic	14.47826087	95	Uganda	12.11111111	131
CHINA	18.85185185	15	Morocco	15.81481481	57	Slovak Republic	14.41666667	96	Malawi	11.88888889	132
Turkmenistan	18.84	17	Suriname	15.81481481	57	Egypt, Arab Rep.	14.33333333	97	Namibia	11.88888889	132
St. Lucia	18.77777778	18	Belgium	15.70588235	59	Kuwait	14.33333333	97	Ethiopia	11.66666667	134
Fiji	18.7037037	19	Hungary	15.66666667	60	Armenia	14.28	99	Angola	11.51851852	135
Lebanon	18.55555556	20	AUSTRALIA	15.59259259	61	Tonga	14.25925926	100	Burkina Faso	11.51851852	135
Seychelles	18.33333333	21	Guyana	15.59259259	61	Antigua and Barbuda	14.11111111	101	Norway	11.51851852	135
Georgia	18.28	22	Austria	15.51851852	63	Rwanda	13.96296296	102	Tanzania	11.51851852	135
Vanuatu	18.18518519	23	Brunei Darussalam	15.51851852	63	Papua New Guinea	13.88888889	103	Cabo Verde	11.44444444	139
ARGENTINA	17.96296296	24	Libya	15.51851852	63	Lithuania	13.8	104	Congo, Rep.	11.44444444	139
French Polynesia	17.96296296	24	SOUTH KOREA, REP.	15.51851852	63	Cote d'Ivoire	13.74074074	105	Denmark	11.22222222	141
Dominican Republic	17.88888889	26	Belarus	15.48	67	Guinea	13.74074074	105	Mozambique	11.22222222	141
Honduras	17.88888889	26	Iran, Islamic Rep.	15.44444444	68	Yemen, Rep.	13.74074074	105	Lao PDR	11.07407407	143
Panama	17.88888889	26	Romania	15.44444444	68	Burundi	13.51851852	108	Finland	11	144
Samoa	17.88888889	26	Cameroon	15.37037037	70	INDIA	13.51851852	108	Senegal	10.92592593	145
BRAZIL	17.74074074	30	Kyrgyz Republic	15.16	71	Latvia	13.48	110	Central African Republic	10.7037037	146
Montenegro	17.72727273	31	SAUDI ARABIA	15.14814815	72	GERMANY	13.37037037	111	Lesotho	10.7037037	146
Syrian Arab Republic	17.59259259	32	TURKEY	15.14814815	72	UNITED KINGDOM	13.2962963	112	Botswana	10.62962963	148
Barbados	17.46153846	33	UNITED STATES	15.14814815	72	Azerbaijan	13.16	113	Iraq	10.62962963	148
Jordan	17.37037037	34	Croatia	15.08	75	Zambia	13.14814815	114	Eritrea	10.47368421	150
Vietnam	17.2962963	35	Ghana	15.07407407	76	Comoros	12.92592593	115	Chad	10.33333333	151
Moldova	17.24	36	New Caledonia	15.07407407	76	SOUTH AFRICA	12.92592593	115	Sweden	10.33333333	151
New Zealand	17.22222222	37	Bolivia	15	78				Haiti	10.25925926	153
Trinidad and Tobago	17.16	38	MEXICO	15	78				Niger	10.18518519	154
Mauritius	17.14814815	39	Switzerland	15	78				Nepal	9.962962963	155
FRANCE	17.07407407	40							Mongolia	9.074074074	156
Jamaica	17.07407407	40							Mauritania	9	157

Each country in the average ranking scheme was colour-coded according to world region,

WORLD REGIONS
AFRICA
THE AMERICAS
ASIA-PACIFIC
EUROPE
MIDDLE EAST & CENTRAL/WESTERN ASIA

The percentile-based index score 'cut-off' levels were as follows, ≥ 17.07407 (highest total exposure potential), 17.07407 > Average EIR-IS > 12.85185 (medium-to-high total exposure potential), and ≤ 12.85185 (lower total exposure potential). The medium-to-high index distribution range was further subdivided into 'high medium' (17.07407 > Average EIR-IS ≥ 15), and 'medium-to-lower medium' (15 > Average EIR-IS > 12.85185) The average rank for total exposure potential (by country) for the 27-year time series was led by Belize the country ranked number 1 for single highest average total exposure potential and Highest Appreciable public health concern worldwide, and ended with Mauritania (ranked 157) deemed the country with the lowest average total exposure potential and Lowest Appreciable public health concern. Forty nations were rated as having the highest pesticides total exposure potential with an average EIR-IS of 18.58. Among them nearly 38% and 23% were from the Americas and Asia-Pacific region, respectively. The proportion of countries with 'high medium' and highest total exposure potential (nearly half, 49.7%), corresponding to Appreciable and Highest Appreciable public health concern, had an average EIR-IS of 17.25.

The average EIR-IS for nineteen G7/G20 nations evaluated by PCE-ISys was 15.49. The index scores for the majority (nearly 63%) were characterised by 'high medium' to highest pesticides total exposure potential. Indonesia was the only country among the G7/G20 to rate at a level of Lower Appreciable public health concern. Italy, China, Argentina, Brazil, and France ranked the highest among G7/G20 nations their average index scores falling within the upper 25th percentile for total exposure potential.

A large swath of countries within the Americas trended higher in total exposure potential while a substantial number of countries in the African continent ranked among the lowest. This particular occurrence is consistent with the comparative trend in average annual pesticides-use rates among world regions, where average annual pesticides use is among the highest for countries within the Americas, while lowest (on average) in Africa (Food and Agriculture Organization, 2021).

The region with the highest proportion of countries rated as being an Appreciable or Highest Appreciable public health concern was the Americas (97%), followed by the Middle East region at nearly 90%, and Europe and Asia-Pacific at 81% and 66%, respectively.
Africa was the only world region where the majority of countries had a rating of Lower Appreciable public health concern (nearly 53%).

PCE-ISys scoring and rating distributions by world region appear to correspond to the Wachter and Staring pesticides-use guideline that argues that average annual use rates (of pesticides active ingredient) are likely associated with a country's level of economic development, and degree of regulatory sophistication (World Health Organization, 1990).

4 PCE-ISys TESTING APPLICATION(S) DISCUSSION

4.1 Worldwide Pesticides Total Exposure Potential

By all measure, PCE-ISys evaluation metrics demonstrated that worldwide there continues to be reason for public health concern related to the potential for pesticides exposure, and the magnitude of potential exposure arising from agricultural economy and environment (by country).

4.1.1 Exposure Ratio Index and ERI Analysis (1990 – 2016)

As previously discussed, PCE-ISys is an evaluation model that is designed to gauge the potential public health implications associated with collective policy decisions that drive agricultural economic growth and development at the macro-level. The net upward, global trend in Exposure Ratio Index (+16%) indicates that collective economic governance decisions, and its potential influence on farm-level economic preferences are likely contributing factors to the global increase in pesticides total exposure potential.

The ERI Analysis results support the argument that pesticides total exposure potential, and its likely public health implications are endemic, and warrant re-evaluation of the criteria used to set agroeconomic development policy. The PCE-ISys global indexing results, i.e., an average Margin of Exposure Ratio Index at half of 80%, an ERI-TD Ratio of 2, and a global ERIQ 300% above trend in ERI_{min} give rise to concern about the extent of potential human exposure inferred from the degree of worldwide usage of crop protection chemicals. The fact that the indexing estimates between 1990 - 2016 showed that sixty-three percent of nations contributed to worldwide total exposure potential associated with Appreciable public health concern, or higher, and that relative exposure potential increased by 78% over the twenty-six-year span offers further evidence for concern of health and environment over the increase in global aggregate pesticides usage.

The economic benefits of industrialised agriculture have a proven positive, transformative effect, but the trade-offs with health and environment point to a continued failure to view public health as integral to agroeconomic policy and planning; offering at least some insight as to possibly why pesticides exposure-related impacts persist worldwide.

Finding workable solutions to reducing pesticides-related risk continues to be an outward challenge. The PCE-ISys indexing results demonstrated that, from a global perspective, population-level pesticides total exposure potential is likely symptomatic of the collective growth-orientated policy manoeuvring characteristic of highest, high, and even medium total exposure potential g-AEES. Not unlike the worldwide consensus reached acknowledging the necessity to fight the climate crisis through a collective global effort, the PCE-ISys indexing analysis outcomes for this project signal a need for finding the collective social and political will to adopt more harmonised policy development paradigms. Such policy and planning frameworks could, for example, see that estimations of the overall economic health cost(s) of pesticides-related impacts be integrated into macro-level agroeconomic governance processes as impetus for mandating risk reduction guidance measures into policy (unlike, for example, the voluntary nature, or even absence of agricultural GAP-IPM policy in many developing countries)(European Parliament, 2021; Obilo et al., 2006).

PCE-ISys offers civil society, governmental bodies, as well as regional and world intergovernmental organisations an assessment 'lens' by which to clearly recognise that 'business-as-usual' economic growth-driven political governance is inseparable from potential population-based pesticides exposure, and in most cases exacts a profound long-term cost to human health, well-being, and ecological integrity on a global scale; and that when the scope of policy-informing evidence is broadened to include issues of public health, macro-level governance decisions can be better fashioned to promote sustainable development.

4.2 Country Ranking Profiles for Pesticides Total Exposure Potential

The PCE-ISys evaluation model outputs, PCE-IS, $Pi_{exp}R$ (and Adj-$Pi_{exp}R$), EIR-IS, and corresponding ERI Analysis outcomes demonstrate that the potential pesticides exposure-related profile worldwide (and by individual country) remain an on-going concern that must addressed,

- The collective results of the PCE-ISys Ranking Profiles (by country) relative to ERI over the time-series showed that for every 5 nations three had total exposure potential scores associated with ratings of Appreciable or Highest Appreciable public health concern, of which 64% scored an EIR-IS ≥ 17. The indexing outcomes demonstrate that systemic pesticides use for the majority of countries throughout the world remains expansive, and likely problematic to health and environment; and that almost every country from all the major world regions, and their sub-regions evaluated as a part of the time series (with the exception of Africa), over the long-term, face a potential public health reckoning associated with agricultural pesticides usage in the context of each respective country's collective agroeconomic policy decisions.
- The indexing outputs also helped facilitate analyses based on country-to-country comparisons. Such comparative evaluations aided in pointing out that the (per capita) magnitude of daily potential exposure could be affected by pesticides usage, both in terms of use rates, and tonnage, factors that are dictated by macro-level governance and farm-based decision making. For example, the 2016 Ranking Profile for Malaysia (Adj-$Pi_{exp}R$ = 2893) indicated that the average annual pesticides-use rate was, as expected, very high at 8 kg/ha based on the Wachter & Staring use guidelines, but it turns out that pesticides tonnage for the country was equally considerable compared to the consumption rate (in relative terms), due to agricultural land allocation nearing 7.5 million hectares (EIR_{score} = 5); whereas Belize (Adj-$Pi_{exp}R$ = 1712) for that same year also had an exceedingly high use rate (10.5 kg/ha), but coupled with relatively lower crop productivity of 92, and an agricultural land allocation 235-times below that of Malaysia. Belize's total farm land area in relation to its relatively small population (368,400) was a key contributing factor in its relatively high FLAC output; that in turn helped amplify its Pi_{exp} by way of an already substantially high PCPr, pointing to use rate, more so than tonnage as one reason for the country's high level of exposure potential (data available at www.threepercentearth.org).

- Of 19 G7/G20 countries evaluated under PCE-ISys eighteen scored medium-to-high, or highest average total exposure potential for the 27-year time series, indicating that the size of a country's economy is likely to play at least some role in affecting pesticides total exposure potential. At the same time, the ranking results suggest that country economy size is unlikely to be directly correlated with pesticides total exposure potential. For example, the United States has the world's largest economy, and yet its average EIR-IS of 15 (although rated as an Appreciable public health concern) denotes a 'high medium' level of total exposure potential while Argentina (having one of the smallest economies among the G20) demonstrated an average EIR-IS of nearly 18 (within the upper 25th percentile), and rated as having a highest level of appreciable public health concern. Conversely, China (the world's second largest economy) scored an average EIR-IS of nearly 19 (among the highest worldwide), while South Africa (the smallest economy among G20 nations) had an average EIR-IS of 12.925, an index bordering on lower total exposure potential.
- It can be inferred from the PCE-ISys output results that countries with smaller, transitioning economies, i.e., those with growing and/or emerging markets appear most vulnerable to higher levels of pesticides related potential exposure on a population-basis, while poorer more underdeveloped economies characterised by higher proportions of subsistence agriculture appear less apt to rely on widespread pesticides use. For example, 'transition economy' countries such as Malaysia, Costa Rica, Fiji, and Ecuador all of which had average EIR-IS ≥ 18 ranked among the top 10 worldwide for highest total exposure potential in 2016, while smallest economy countries for that same year included nations such as, Lao PDR, Comoros, Mongolia, and Tanzania (with average EIR-IS ranging from 7 to 13). The indexing results, however, showed exceptions to this argument, among them countries such as Italy, Portugal, and Spain characterised by relatively higher degrees of economic development also demonstrated highest levels of total exposure potential. Conversely, all Scandinavian countries evaluated under PCE-ISys consistently demonstrated lower pesticides total exposure potential. The PCE-ISys indexing results suggest that g-AEES-driven total exposure potential likely arises from a multitude of possible indicators, in addition to those that form the basis for g-AEES. Such indicators may include, overall regulatory capacity (by country), political and/or cultural perspectives about pesticides use in agricultural economy, the degree of country wealth and/or human development, the rule of law or governmental corruption, and pesticides misuse or overuse. From a policy perspective it would certainly be useful to have insight into the profile of relevant social and economic indicator(s) (by country) to determine what factors (or combination of factors) may serve to facilitate pesticides total exposure potential in the context of its respective g-AEES.

5 CONCLUSION

Striving to achieve global food security goals à la SDG 2 is an endeavour prompted by worldwide food demand based on continuing population growth, particularly throughout developing regions of the planet. At the same time, it behoves governments and economic participants of food producing systems alike to take into consideration the potential long-term pesticides related consequences from global industrialised food production. Chemical farming pesticides have become, and continue to be a standard economic input for agricultural production. Unfortunately, the empirical weight-of-evidence undeniably points to substantial health risk(s) associated with acute, and long-term consumer, occupational, and environmental exposure to crop protection chemicals. Given this fact, developing meaningful ways to identify and evaluate the impacts *before* they occur must be granted outward prioritisation for both human health and sustainable development purposes.

The *Pesticides Consumer-Environmental Indexing System* (PCE-ISys) is a novel policy decision-support evaluation scheme that (by design) embraces the idea of precaution as tenet, and does so by focusing on the concept of the 'potential' for pesticides exposure, and the magnitude of 'potential' exposure on a per capita basis in relation to its respective 'generalisable agroeconomic environmental system,' i.e., pesticides usage, crop productivity, agricultural land-use, and human population.

The indexing results of the PCE-ISys project allows one to reasonably surmise that future pesticides-related impacts can be prevented, and health risks reduced when macro-level governance decisions are tethered to salient evidence-based information used to integrate public health and agricultural economy within policy and planning frameworks. The analysis outcome of the global indexing results, as well as the ranking profiles also raise potential questions about how social and economic indicators may be used to pique research interest in sustainable development policy with a particular focus on issues of ecological integrity, sustainable farming, and the promotion of human health and well-being. Such future research is essential in finding better ways to meet human consumption demand while balancing the need for maintaining, and enhancing the natural environment.

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