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Assessing Global Needs When Identifying Potential Engineering for Global Development Projects

With limited time and resources available to carry out Engineering for Global Development (EGD) projects, it can be difficult to know where those resources should be allocated to have greater potential for meaningful impact. It is easy to assume that projects should occur in a particular location based on personal experience or where other development projects are taking place. This can be a consideration, but it may not lead to the greatest social impact. Where to work on a project and what problem to work on are key questions in the early stages of product development in the context of EGD. To aid in this process, this article presents a method for assessing global needs to ensure thoughtful use of limited EGD resources. We introduce a method for identifying locations where there is human need, gaps in technological achievement, and what the work environment is in a country. Results of the method are compared to what countries receive the most foreign aid dollars per capita. Measures were calculated using the principal component analysis on data from development agencies. These results can help practitioners in selecting where to undertake development projects with an eye toward targeting locations that may yield high levels of social impact. [DOI: 10.1115/1.4052223]

Keywords: design for humans, design for X, design process, sustainable design

1 Introduction

Many engineers seek to improve some aspect of a person's life through design. Practitioners of Engineering for Global Development (EGD) have a more specific objective of seeking to improve the lives of people in under-served communities where basic human needs are not being met [1]. Many challenges are faced by practitioners in the EGD space to avoid the failure of projects [2,3]. One way for an EGD project to maximize social impact is to find an opportunity where there is a need in the market, an opportunity for innovation, and favorable regulatory and logistical conditions to perform a project within a particular country. Much of the current literature on the success of global development projects focuses only on factors occurring after the selection of the location of the project [4,5]. Many projects are chosen based on case studies, personal experience, or where funding for development can be secured. Other literature has used statistical methods to help identify what industry sectors to work within that are correlated with improvements in the UN human development index (HDI) [6].

The present article introduces a model to assess the fulfillment of human needs, gaps in technological achievement, and what countries have a favorable regulatory and logistic environment. This model is a quantitative tool that complements qualitative methods to aid in EGD project location selection. It is important to recognize that engineers do not always have full control over where they work; therefore, the method presented here, while having an important influence on EGD, may be used by anyone involved in early-stage project selection in the EGD space. This includes industry practitioners, funders, academics, NGO workers, student innovation teams, and others. Although there may be varying motivations for undertaking an EGD project, such as a government trying to gain influence in a region for political gain, this article only focuses on the assessment of basic human needs, technological achievement, and work environment.

Hundreds of country-level indicators can be found from organizations such as the World Bank [7] and the UN [8]. With the large amounts of data, it can be difficult to know what indicators are most important to selecting a location for a project. There are 232 indicators for measuring the UN Sustainable Development goals alone [9]. This article uses a statistical approach to reduce the variable space with the principal component analysis (PCA) [10]. Similar approaches have been used to create models for socioeconomic indices [11], health care [12], project success factors, and measuring technological capabilities [13]. The advantage of using a statistical approach such as PCA is that the weighting of different factors of the model are determined objectively rather than subjectively [14].

To create this model, certain assumptions needed to be made. It was assumed that for lasting project success to occur, there would need to be a favorable business and regulatory environment in a country to conduct operations. This will favor countries with more developed regulatory environments. This does not mean to dissuade from undertaking projects in places with less-developed business and regulatory conditions, but it is to help practitioners be aware of potential hurdles to project success. Projects in these countries, where it is the most difficult in which to perform, may best be undertaken by large organizations with the resources to overcome more difficult political, regulatory, and logistical environments. Other literature stresses the importance of finding the right partner organization [15], while this is an important factor for EGD projects, it is outside the scope of the models contained in this article due to the difficulty of available country-level data on potential partners. There will be many qualitative and quantitative factors that go into EGD project selection. The value of a quantitative model such as the one presented in this article is helpful in narrowing down the number of potential countries to perform a project from many possible countries to a few countries where further investigation should be performed. Both quantitative and qualitative tools should be used in the project selection process.

Current literature on project location selection is directed to business practices, but insights from this literature can help inform EGD project selection. Consideration of political [16], logistical [17],

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infrastructure [18], and regulatory factors [19] has been put forth, and these factors were considered for the models contained in this article.

The overall model presented in this article contains three portions: an assessment of deficiencies in basic human needs, identifying gaps in technological achievement, and an assessment of what countries are most favorable to conduct a project. Indicators used in the model were from the United Nations COMTRADE Database [20], World Bank [7], World Economic Forum [21,22], World Happiness Report [23], and AidData [24]. The overall model was created with submodels in the following areas:

(1) *Meeting of basic human needs*
  (a) Existence needs
  (b) Relatedness needs
  (c) Growth needs
(2) *Technological achievement*
  (a) Scientific innovation and invention
  (b) Penetration of older technologies
  (c) Penetration of recent technologies
  (d) Exposure to external technology
(3) *Work environment*

1.1 Meeting of Basic Human Needs.

The meeting of basic human needs portion of the model was based on the existence, relatedness, and growth (ERG) model [25]. This theory draws upon the more well-known Maslow's hierarchy of needs [26], but has better empirical evidence to support it than Maslow's method [27]. *Existence needs* involve physiological desires such as hunger, thirst, air, safety, working conditions, shelter, and sleep. *Relatedness needs* involve sharing thoughts and feelings, social networks, family, and sense of connection. *Growth needs* involve a person bettering him or herself, or the environment around them.

It is important to note that the selection of indicators does introduce bias into any model. To minimize bias in this model, the selection of indicators for the meeting of basic human needs was determined by utilizing keyword filtering and a *consensual assessment technique* [28] on all World Development Indicators from the World Bank. Four EGD practitioners were selected for the consensual assessment technique. These practitioners all have multiple experiences in EGD projects, management, and research. Three of four have significant industry experience, with the fourth having mainly academic experience. The group included both US and non-US citizens, and the mean age of the group was 38 years. Keyword filtering was carried out in python to filter from over 1,200 indicators to 343. The remaining indicators were categorized by the EGD practitioners independently using a Likert scale for how connected an indicator is to the three levels of the ERG model. The order of the indicators was randomized, and steps were taken to limit the time spent in one categorization session to prevent decision fatigue. Practitioners were trained and given common definitions for the ERG model and a common rubric for levels of connectedness. After each practitioner completed the categorization independently, results were analyzed for agreement. Practitioners then used a method of *investigator triangulation* [29] to discuss where there was not alignment in the categorization and reasons for categorization to understand if there was a new perspective that one or more practitioners had not thought of. During the discussion, practitioners were allowed to anonymously change the categorization or keep the initial categorization. If 75% or more of the practitioners rated an indicator as connected to an ERG level, it was included in the model.

1.2 Technological Achievement.

In the EGD community, it is helpful to find potential projects with the chance of technological innovation to utilize the engineering skills of the design team. This applies to those looking to implement a technological innovation as an intervention and may not help in identifying opportunities for interventions not focused on technological solutions. To understand where there are gaps in the technological achievement of a particular country, a method was adapted from a report published by the World Bank [14]. Slight changes were made in what was measured due to the changing technology environment since 2008, when the report was published. These changes were based on the increased utilization of the Internet in the world and the decline of landline use [30]. This allows for the use of quantitative results to show where the largest gaps in technological achievement exist between highly developed countries and emerging markets. The technological achievement model includes portions for scientific innovation and invention, penetration of older technologies, penetration of recent technologies, and exposure to external technology. For specific uses of the model, a user can easily alter the measures used in the technological achievement score to better align with his or her specific need by following the methods outlined in Sec. 2.

1.3 Work Environment.

The success of a project will depend on being able to implement it in a particular country; therefore, it is important to work in a country that is open to foreign investment and the operations of international NGOs. Just as foreign investors often search for locations that are characterized by political stability and adequate infrastructure to minimize sunk costs associated with doing business in certain parts of the world, we assume that countries with similar characteristics will decrease the operational costs of engineers engaged in global development projects. For the purposes of this article, the work environment portion of the model is based on helping a small organization that is foreign to potential countries and unfamiliar with the nuances of a particular location. With the right knowledge of the particular workings of a country, the potential obstacles for performing a project may be overcome. The basis of the work environment portion of the model was the World Bank's ease of doing business score with additional indicators such as the incidence of corruption, openness to foreigners, and infrastructure ratings. This enables quantitatively assessing the work environment within a particular country.

2 Research Method

The research followed the general process of data collection, data formatting and normalization, accounting for missing data, principal component analysis, creating country heat maps as described below, and interpreting the results for integration into project selection workflows.

2.1 Data Collection.

Indicators needed to be collected from multiple agencies to construct the model. The World Bank and UN COMTRADE have a robust application programming interface, so the data collection can be automated once the script is written. Data from the World Economic Forum, World Happiness Report, and AidData are needed to be first downloaded as comma-separated value (CSV) files before processing. Data were sorted according to ISO Alpha-3 [31] country codes instead of the country names, so the data grouping remains consistent. Data were compiled in MATLAB for processing.

2.2 Data Preparation.

For each indicator, the most current known value for a particular country was used for the analysis. It was necessary to use the most current known value in place of data from the same year for each country due to incomplete data sets for each year. To standardize measurements and to increase the comparability, all indicators were scaled to a percent of population, a percentage of GDP, or a percent of land. All indicators were normalized to a zero to one scale, with one being the highest performing country and zero being the worst performing country. This was done according to the scoring function provided in Eq. (1). Here, the score for indicator j for country i is s_{ij}.

$$s_{ij} = \frac{S_{ij} - \text{Min } S_j}{\text{Max } S_j - \text{Min } S_j} \tag{1}$$

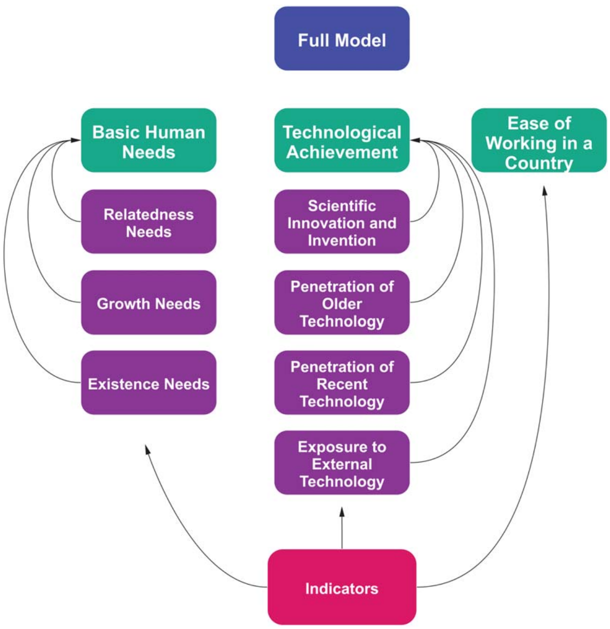

Fig. 1 PCA process flow

2.3 Missing Data. Because of the nature of development data, complete data sets are rare. Very few of the indicators used for the models in this article had complete data for each country. To preserve the integrity of the model while accounting for missing data, multiple strategies [32] were employed. The first method was a carry forward method. For this method, if a country had data for a previous year, but not the current year, the last known data point was used in the analysis. The second method was a list-wise deletion. For this method, if an indicator was missing data for more than 25% of the countries, the indicator was deleted from the model. To impute the remaining missing values, multiple imputation [33] was implemented. Multiple imputation was selected because it uses the available data to perform a linear regression to estimate the missing value. The multiple imputation was carried out using the MICE package [10] in R with predictive mean matching as the multiple imputation method. Multiple imputation allows for maintaining the overall mean of a given indicator without reducing the variance.

Table 1 PCA summary statistics

Model portion	% Variance explained	p value (Bartlett test)
Basic human needs	97.444	<0.0001
Existence needs	46.59	<0.0001
Relatedness needs	44.78	<0.0001
Growth needs	45.48	<0.0001
Technological achievement	50.77	<0.0001
Innovation and invention	89.81	<0.0001
Penetration of older technology	38.31	<0.0001
Penetration of recent technology	40.20	<0.0001
Exposure to external technology	59.96	<0.0001
Work environment	64.37	<0.0001

2.4 Principal Component Analysis. PCA is a method of reducing the dimensionality of data. This allows taking a large set of variables such as those in this model and reducing them to a few variables. PCA does this by calculating linear combinations of the variables that will explain the largest portion of the variance

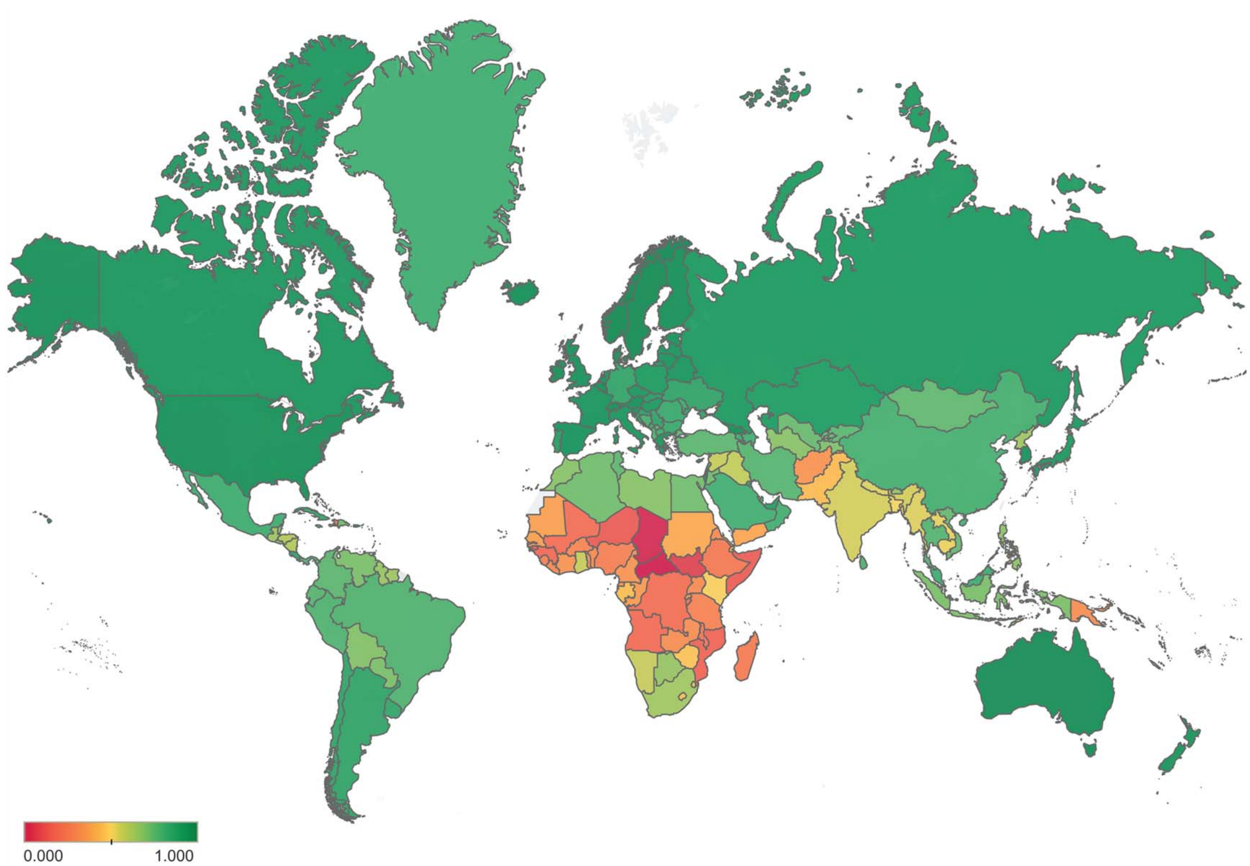

Fig. 2 Basic human need score; lower scores indicate that basic needs are not met as well as those with larger scores

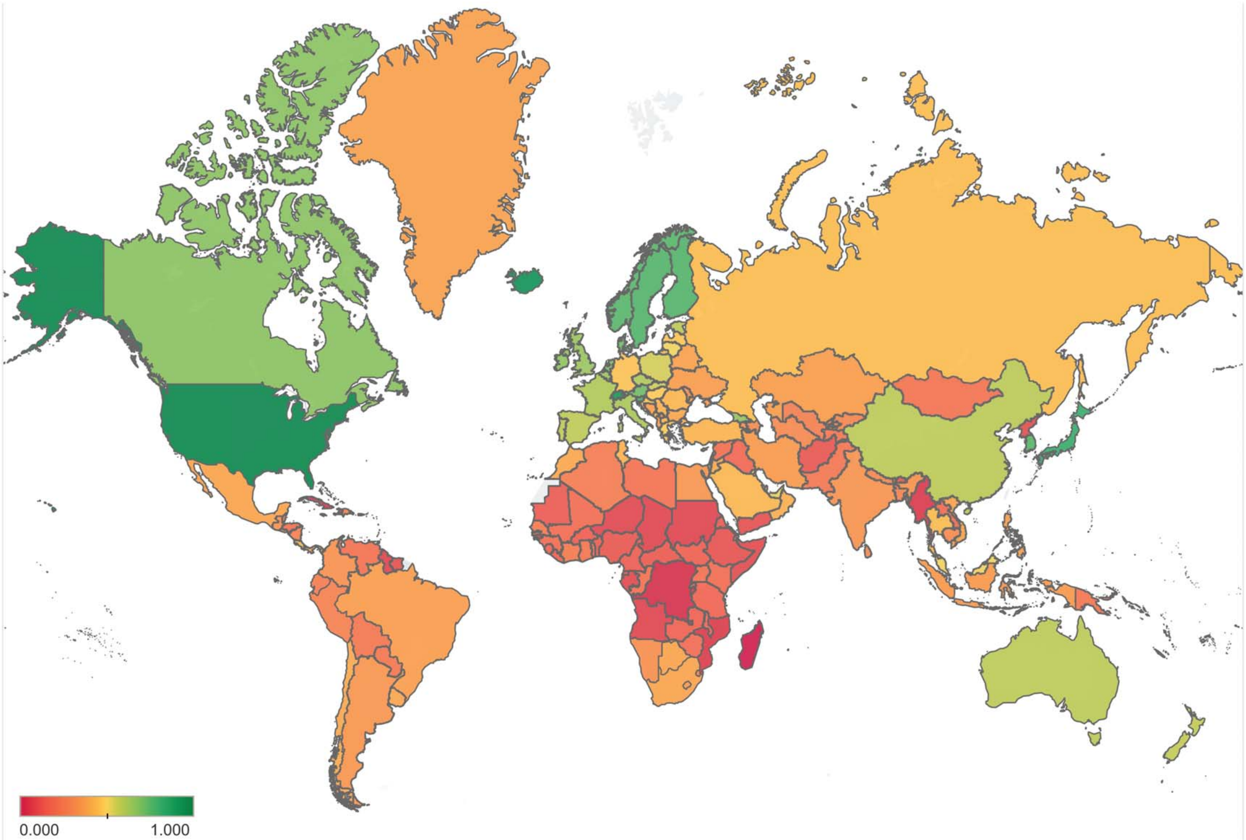

Fig. 3 Technological achievement score; lower scores indicate lower technological achievement

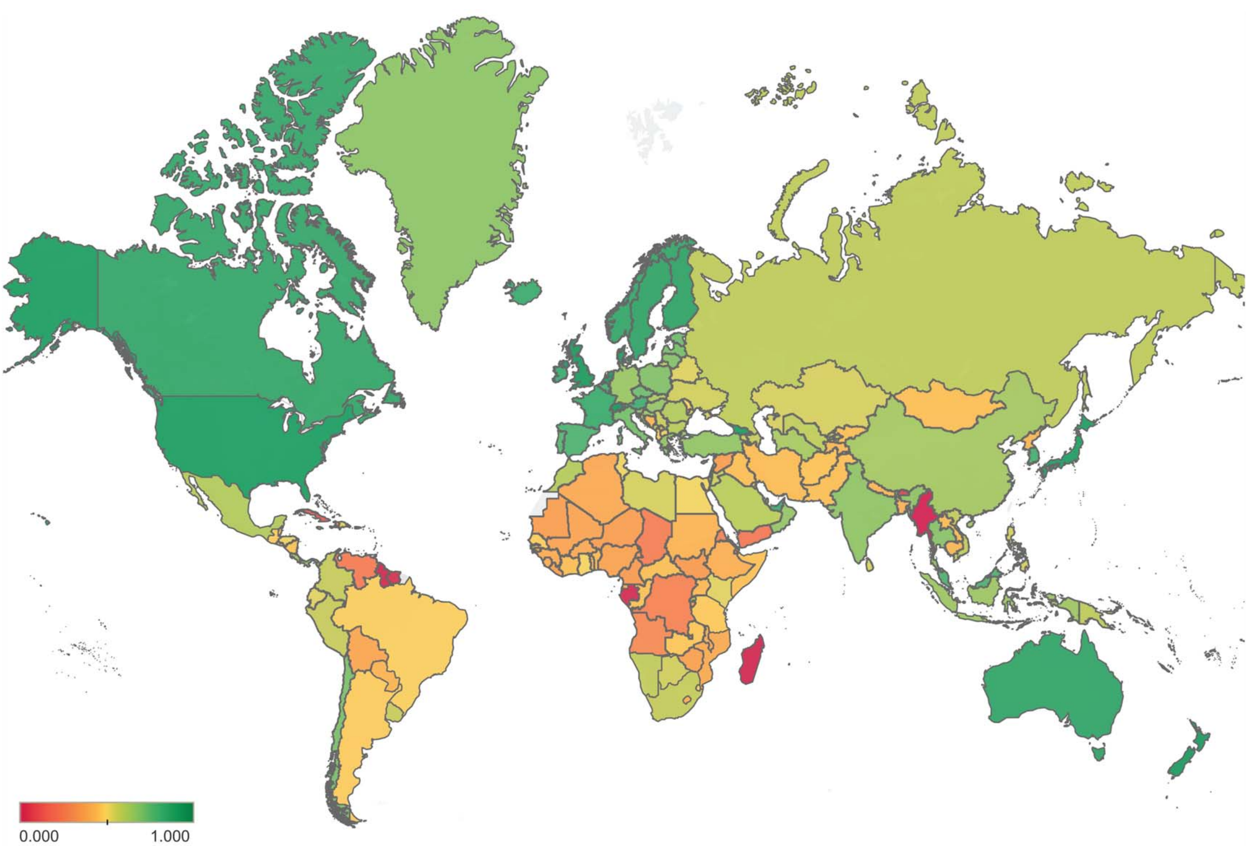

Fig. 4 Work environment score; higher scores indicate more favorable working environment

Table 2 Least developed country scores

Country	Meeting of basic human needs	Technological achievement	Work environment
Afghanistan	0.33	0.12	0.46
Angola	0.18	0.07	0.30
Bangladesh	0.50	0.28	0.42
Benin	0.29	0.14	0.44
Bhutan	0.66	0.13	0.07
Burkina Faso	0.27	0.15	0.39
Burundi	0.21	0.05	0.34
Cambodia	0.51	0.31	0.44
Central African Republic	0.00	0.13	0.46
Chad	0.01	0.07	0.25
Comoros	0.45	0.19	0.59
Democratic Republic of the Congo	0.20	0.03	0.27
Djibouti	0.44	0.19	0.29
Eritrea	0.30	0.14	0.26
Ethiopia	0.23	0.11	0.41
The Gambia	0.39	0.21	0.45
Guinea-Bissau	0.18	0.29	0.37
Guinea	0.13	0.07	0.40
Haiti	0.26	0.04	0.34
Kiribati	0.61	0.19	0.51
Lao PDR	0.52	0.19	0.45
Lesotho	0.45	0.35	0.41
Liberia	0.29	0.16	0.37
Madagascar	0.24	0.00	0.01
Malawi	0.22	0.17	0.40
Mali	0.19	0.20	0.38
Mauritania	0.36	0.13	0.36
Mozambique	0.16	0.05	0.40
Myanmar	0.53	0.04	0.00
Nepal	0.53	0.30	0.43
Niger	0.13	0.08	0.36
Rwanda	0.36	0.19	0.60
Sao Tome and Principe	0.52	0.20	0.38
Senegal	0.36	0.24	0.49
Sierra Leone	0.25	0.17	0.41
Solomon Islands	0.46	0.22	0.36
Somalia	0.13	0.09	0.46
South Sudan	0.06	0.15	0.35
Sudan	0.39	0.07	0.42
Tanzania	0.27	0.17	0.48
Timor-Leste	0.49	0.26	0.65
Togo	0.30	0.19	0.42
Tuvalu	0.63	0.31	0.50
Uganda	0.30	0.20	0.44
Vanuatu	0.54	0.36	0.56
The Republic of Yemen	0.38	0.10	0.23
Zambia	0.31	0.16	0.47

in the data. With the models contained in this article, a single principal component was used to calculate the next portion of the model. For example, for the *existence needs* portion of the model, the indicators of birth rate, access to basic water, access to family planning, adolescent birth rate, undernourishment rate, level of water stress, mortality rate due to pollution, mortality rate due to water sanitation and hygiene, and percent population with access to electricity are used for PCA to produce a single variable from the first principal component. This gives one variable for existence needs. The advantage of PCA is that weights of each indicator in the model are determined statistically and methodically rather than subjectively choosing how each variable is weighted within a model.

The PCA was performed using JMP software [34]. Indicators were input into the PCA to create each submodel in the overall model, and the submodels were then input into a second PCA to create the three main portions of the model. The work environment portion did not contain any submodels, so the indicators were used directly in a single PCA for that portion of the model. See Fig. 1 for a visual description of the PCA workflow. These social issues that are also incorporating technological achievement and the complexities of human need are so multilayered that all of the information that resulted from the expert review of indicators. For the sake of publication simplicity, it was decided to not simplify the complexities of the model.

Results of the PCA in Table 1 indicate that the PCA was an appropriate process for variable reduction. For each PCA that was performed, the percent variance explained was >38%. The p values from the Bartlett test were all <0.0001, indicating that there is a significant difference between the correlation of the variables with that of the identity matrix. This indicates that there is evidence for the use of these indicators for variable reduction. If there were high p values for the Bartlett test or if the percent of variance explained was low, this would indicate that using PCA is not a suitable method for creating this model. For the equations and weightings of coefficients in the PCA, see Eqs. (2)–(11). Definitions for the variables can be found in Nomenclature section. The coefficients in the equations inform the EGD project selectors of the relative importance of each indicator in the PCA score. From a practical perspective, this means that project selectors can know which indicators (e.g., death rate, crop production index, prevalence of anemia among children) best explain the difference between potential locations, in terms of need, potential for innovation, and working environment. A higher coefficient shows that a given indicator is more important for explaining the variance than an indicator with a lower coefficient.

$$N = 0.105N_1 + 0.143N_2 + 0.134N_3 \tag{2}$$

$$\begin{aligned} N_A = {} & 0.450N_{A1} + 0.608N_{A2} + 0.730N_{A3} - 0.161N_{A4} \\ & + 0.020N_{A5} + 0.743N_{A6} + 0.574N_{A7} + 0.519N_{A8} \\ & - 0.592N_{A9} + 0.802N_{A10} + 0.567N_{A11} + 0.488N_{A12} \\ & - 0.605N_{A13} - 0.456N_{A14} + 0.052N_{A15} - 0.699N_{A16} \\ & - 0.379N_{A17} - 0.175N_{A18} - 0.184N_{A19} + 0.809N_{A20} \\ & - 0.462N_{A21} + 0.732N_{A22} + 0.735N_{A23} + 0.599N_{A24} \\ & + 0.528N_{A25} + 0.595N_{A26} + 0.512N_{A27} + 0.043N_{A28} \\ & - 0.153N_{A29} - 0.193N_{A30} - 0.228N_{A31} + 0.750N_{A32} \\ & + 0.945N_{A33} + 0.836N_{A34} + 0.560N_{A35} + 0.384N_{A36} \\ & + 0.743N_{A37} + 0.717N_{A38} + 0.849N_{A39} + 0.769N_{A40} \\ & + 0.686N_{A41} + 0.762N_{A42} + 0.284N_{A43} + 0.622N_{A44} \\ & + 0.662N_{A45} + 0.647N_{A46} + 0.563N_{A47} - 0.073N_{A48} \\ & + 0.695N_{A49} + 0.469N_{A50} + 0.672N_{A51} + 0.650N_{A52} \\ & + 0.614N_{A53} + 0.627N_{A54} + 0.559N_{A55} + 0.512N_{A56} \\ & + 0.744N_{A57} + 0.779N_{A58} + 0.610N_{A59} + 0.709N_{A60} \\ & + 0.609N_{A61} + 0.930N_{A62} - 0.230N_{A63} - 18.437 \end{aligned} \tag{3}$$

$$\begin{aligned} N_B = {} & 0.974N_{B1} + 0.927N_{B2} + 0.838N_{B3} + 0.960N_{B4} \\ & + 0.660N_{B5} + 0.741N_{B6} + 0.636N_{B7} + 0.701N_{B8} \\ & + 0.904N_{B9} + 0.770N_{B10} + 1.123N_{B11} + 0.719N_{B12} \\ & + 0.951N_{B13} + 0.917N_{B14} + 1.153N_{B15} + 0.869N_{B16} \\ & + 0.978N_{B17} + 0.879N_{B18} + 0.242N_{B19} + 1.138N_{B20} \\ & - 0.229N_{B21} + 0.845N_{B22} + 0.845N_{B23} + 1.283N_{B24} \\ & + 1.354N_{B25} + 1.447N_{B26} + 1.258N_{B27} + 1.273N_{B28} \\ & + 1.007N_{B29} + 1.022N_{B30} + 0.205N_{B31} + 1.192N_{B32} \\ & + 0.840N_{B33} - 0.108N_{B34} + 0.913N_{B35} + 0.112N_{B36} \\ & - 19.472 \end{aligned} \tag{4}$$

$$
\begin{aligned}
N_C = {} & 0.756N_{C1} + 0.868N_{C2} + 0.659N_{C3} + 0.885N_{C4} \\
& + 0.583N_{C5} + 1.095N_{C6} + 0.902N_{C7} + 0.657N_{C8} \\
& + 0.824N_{C9} + 0.458N_{C10} + 0.681N_{C11} + 0.045N_{C12} \\
& + 0.853N_{C13} + 0.853N_{C14} + 0.958N_{C15} + 0.847N_{C16} \\
& + 0.908N_{C17} + 0.820N_{C18} + 0.692N_{C19} + 0.602N_{C20} \\
& + 1.069N_{C21} + 0.355N_{C22} + 0.806N_{C23} + 0.228N_{C24} \\
& + 0.820N_{C25} + 1.190N_{C26} + 1.270N_{C27} + 1.344N_{C28} \\
& + 1.148N_{C29} + 0.985N_{C30} + 0.952N_{C31} + 0.184N_{C32} \\
& + 1.103N_{C33} + 0.844N_{C34} - 0.736N_{C35} + 0.539N_{C36} \\
& + 0.654N_{C37} - 0.106N_{C38} + 0.385N_{C39} - 0.003N_{C40} \\
& + 0.726N_{C41} - 20.007
\end{aligned} \tag{5}
$$

$$T = 0.543T_A + 0.504T_B + 0.377T_C + 0.025T_D \tag{6}$$

$$T_A = 3.491T_{A1} + 9.790T_{A2} - 0.590 \tag{7}$$

$$T_B = 3.308T_{B1} + 0.0005T_{B2} + 4.041T_{B3} + 5.756T_{B4} - 1.400 \tag{8}$$

$$T_C = 5.678T_{C1} + 2.284T_{C2} + 5.144T_{C3} + 1.630T_{C4} - 4.380 \tag{9}$$

$$
\begin{aligned}
T_D = {} & -0.465T_{D1} - 0.106T_{D2} + 18.776T_{D3} \\
& + 19.256T_{D4} + 17.691T_{D5} - 0.195
\end{aligned} \tag{10}
$$

$$
\begin{aligned}
W = {} & 1.745W_{A1} + 1.558W_{A2} + 2.056W_{A3} + 0.265W_{A4} \\
& + 2.295W_{A5} + 2.201W_{A6}
\end{aligned} \tag{11}
$$

To increase the comparability of the different models, scores were normalized from zero to one for each portion of the model. The data were normalized to this scale by using the same process as presented in Eq. (1).

2.5 Visualization. It is important to be able to understand the data from the model and recognize where the greatest needs are in a short amount of time. To facilitate this, heat maps were generated on a world map with the scores from the analysis. These plots are shown in Figs. 2–4. The nuanced nature of project selection means that the quantitative measures contained in this article are just one portion of project selection, and by utilizing a visualization tool like a heat map, this model can be integrated in to existing workflows for project selection.

3 Results

The model calculated scores for basic human needs, technological achievement, and the work environment for each country. A summary of results is presented in Table 2, for the UN list of least developed countries [35].

3.1 Meeting of Basic Human Needs Results. The *meeting of basic human needs* portion of the model largely aligns with the rankings of the HDI. Sub-Saharan Africa contains most of the lowest scoring countries in the world. Chad was the country with

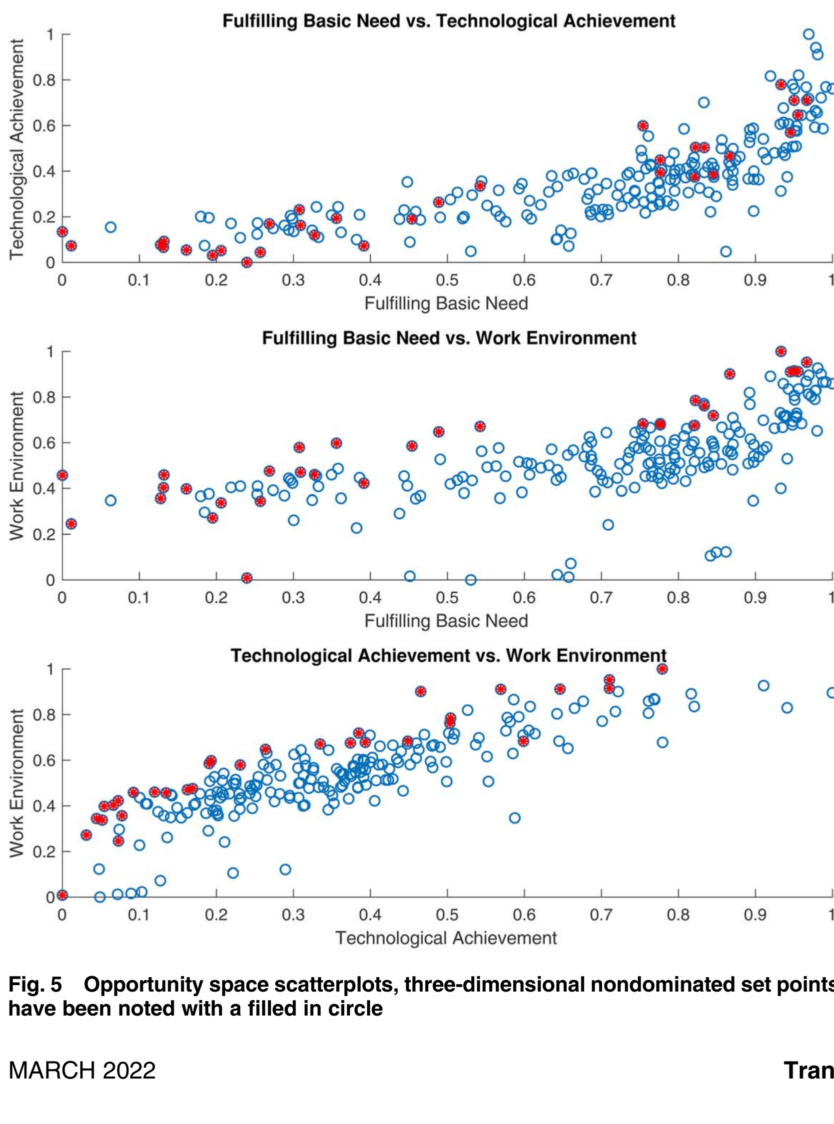

Fig. 5 Opportunity space scatterplots, three-dimensional nondominated set points have been noted with a filled in circle

Table 3 Nondominated set

Country	Meeting of basic human needs	Technological achievement	Work environment
Afghanistan	0.33	0.12	0.46
Burundi	0.21	0.05	0.34
Central African Republic	0.00	0.13	0.46
Chad	0.01	0.07	0.25
Comoros	0.45	0.19	0.59
Democratic Republic of the Congo	0.20	0.03	0.27
Georgia	0.87	0.47	0.90
Greenland	0.82	0.37	0.68
Guinea	0.13	0.07	0.40
Haiti	0.26	0.04	0.34
Hong Kong SAR, China	0.97	0.71	0.95
India	0.54	0.33	0.67
Madagascar	0.24	0.00	0.01
Malaysia	0.82	0.50	0.78
Mauritius	0.85	0.38	0.72
Mozambique	0.16	0.05	0.40
Netherlands	0.95	0.71	0.91
New Zealand	0.95	0.57	0.91
Niger	0.13	0.08	0.36
Panama	0.78	0.39	0.68
Papua New Guinea	0.31	0.23	0.58
Qatar	0.83	0.50	0.76
Rwanda	0.36	0.19	0.60
Singapore	0.93	0.78	1.00
Sint Maarten (Dutch part)	0.75	0.60	0.68
Somalia	0.13	0.09	0.46
Sudan	0.39	0.07	0.42
Tanzania	0.27	0.17	0.48
Thailand	0.78	0.45	0.68
Timor-Leste	0.49	0.26	0.65
United Kingdom	0.96	0.65	0.91
Zambia	0.31	0.16	0.47

the largest deficiency in fulfilling basic human needs, and the Netherlands was the country that best fulfilled basic human needs. See Fig. 2 for results in a map form. This portion of the model differentiates itself from the established indices such as the HDI by including relatedness and growth needs in the model. The inclusion of higher order needs allows for a more holistic approach to the analysis of basic human needs. This model was able to achieve a multidimensional approach to basic human needs by following the ERG framework for what a human needs and then combining data from different agencies to assess the different components of human need.

3.2 Technological Achievement Results. The results of the *technological achievement* portion of the model show the United States being the best performing country. Madagascar scored the lowest on the technological achievement score. It may be assumed that need and technological deficiencies closely correlate, but by comparing the heat maps for *technological achievement* (see Fig. 3) and *meeting of basic human needs* (see Fig. 2), we can see that there is a difference between the two. This difference is statistically significant based on a p value of <0.0001 for both a paired t-test and Wilcoxon signed-rank test. Therefore, we gain value from including both aspects in the model to help identify where there is the most need and where there is the most opportunity for technological innovation. The *technological achievement* heat map shows that there is a low percentage of countries that are at the forefront of technological achievement and there is room for innovation in much of the world.

3.3 Work Environment Results. For an EGD project to have high potential for success, it is important to seek out locations where there is a favorable political, logistical, and business environment, that is, locations with conditions that facilitate the ease of operation for EGD projects. Singapore scored the highest on the scale, while Myanmar was indicated to have the least favorable *work environment*. From inspection of the heat map (see Fig. 4), for the work environment, we see that there are relatively few countries that score high on the index. There will be difficulties in most countries that EGD work is performed in. This model can help practitioners be aware of difficulties before undertaking the project by examining the scoring and underlying data of the model. One shortfall of the current model is that it does not have a metric for conflict within a country. This causes a problem for a country such as Afghanistan that scores in the middle of the work environment scale, but due to ongoing conflict, it may be a difficult place to work. Currently, there are no direct country level quantitative measures of conflict put forth by the United Nations or World Bank. While it may appear to be difficult to find countries with high needs that are easy to work within, there is insight that can be gained from examining the work environment in a country versus how well basic needs are being met.

3.4 Example. For the purposes of discussion, a summary of results is provided for the countries of Uganda, India, Brazil, and the United States (see Table 4). From the example countries, the score aligns with expectations about where the most basic human needs are. The United States scores very well and shows very little deficiency in basic human needs. Brazil scores only somewhat lower, and this is partly due to the disparity between the well-developed southern Brazil and the less-developed northern regions. India is scoring in the middle of the scale, indicating that there is a larger deficiency in fulfilling basic human needs, but not to the extent that is seen in Sub-Saharan Africa. Uganda is scoring on the low end of countries, but is not at the bottom, for fulfilling basic human needs. Not surprisingly, this indicates that there is a larger potential for impact in fulfilling basic human needs there than in India, Brazil, or the United States.

The United States is one of the top performing countries, when considering technological achievement with the highest possible score of 1.00. India and Brazil score very close to one another with scores of 0.33 and 0.36, respectively. This indicates that both of these countries have a similar amount of deficiency in technological achievement. Uganda scored quite low for technological achievement along with most of Africa.

From the example countries provided, it may be surprising that for the work environment, Brazil scores almost as low as Uganda with scores of 0.49 and 0.44, respectively. This is due in part to the fact that Brazil has stricter visa requirements for foreigners visiting the country. Although the United States has strict visa requirements, it still scores high because of the favorable logistic network and business environment. These insights can be ascertained by examining the underlying indicator scores after examining the overall model portion heat map.

This example shows that comparing the fulfillment of human needs, technological achievement, and work environment between potential target locations can provide insights that can be useful when choosing where to work on an EGD project. One can use these heat maps to compare and contrast options for potential projects or to validate the location of current projects by comparing countries in a similar way. This approach when coupled with other factors of project selection can lead to a better understanding of the opportunities available for EGD projects.

4 Opportunity Space Discussion

The nuanced nature of project selection does not allow for the three model portions to be generally and justifiable combined into a single aggregate objective function that is suitable for all decision

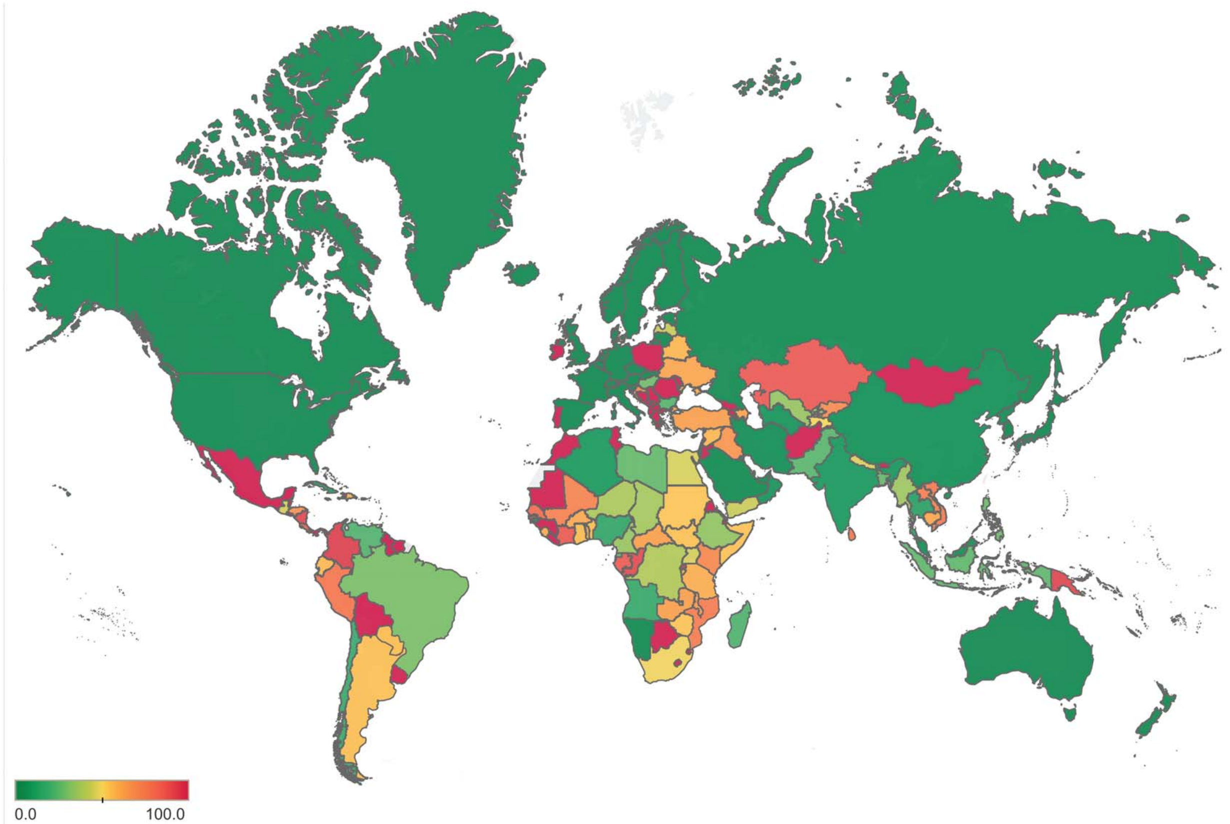

Fig. 6 Average aid dollars per person per year 2009–2013

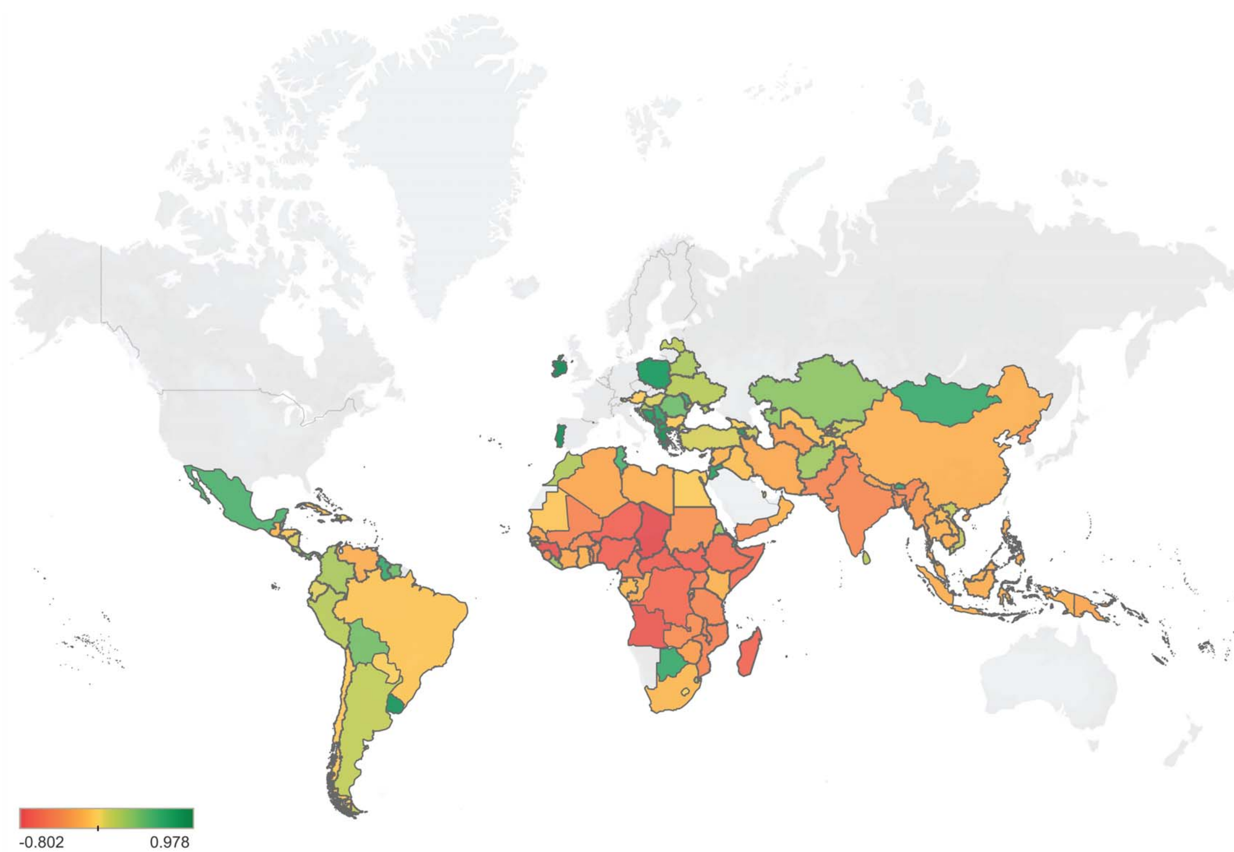

Fig. 7 Aid dollars to fulfilling of basic human need alignment

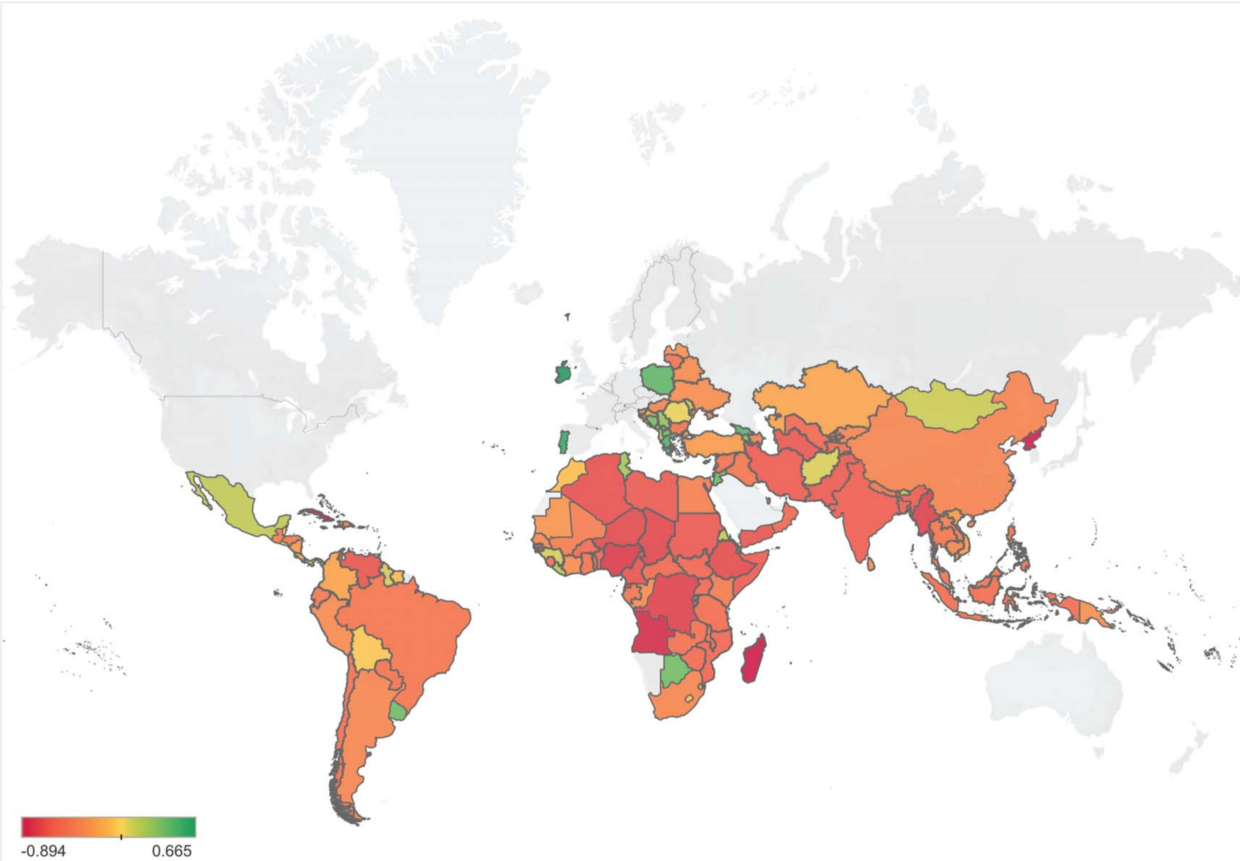

Fig. 8 Aid dollars to technological achievement alignment

makers. To best utilize the data, it is useful to explore the possibilities of where to undertake projects and understand how potential project locations compare to each other. One practitioner may focus on one or two of the portions of this model, while others may want to prioritize the fulfilling of basic human needs over the work environment in a particular country. Decision makers will likely benefit from exploring the opportunity space and make informed choices based on the priorities of the project. By graphically examining the data, a Pareto front can be identified to understand where the nondominated choices lie in the opportunity space (see Fig. 5). The graphical exploration techniques can be employed using two or three of the model portions. The nondominated solution set is presented in Table 3. This graphical exploration combined with the quantitative values helps to identify areas where more effort could be placed. The insight gained from this may help individuals in the EGD community, whether they are from industry, nonprofit, policy making, or academic areas to areas for further investigation. The heat maps, tables, and data that result from this work are best used during the early stages of project selection when examining broad needs. It should be accompanied by other aspects of project selection such as the skills of a team, funding opportunities, and potential partners. Furthermore, by following the methods outlined in Sec. 2, individuals or teams can tailor the approach to their specific skills by adding other indicators to the analysis and performing the PCA again. Results can continue to be updated with new information to match the current world conditions as time progresses.

To understand if the model presented in this article, regarding impact opportunity, lines up with where development projects are taking place, we compiled project level aid data from over 90 organizations and took a yearly average for the years 2009–2013 while normalizing for the population. This gives the average number of aid dollars (current USD) per person per year, see Fig. 6. To understand if there is alignment between the expected aid dollars per capita and the assessment of the fulfillment of basic human needs and technological achievement, new heat maps were created with aid dollars per capita and the meeting of basic human needs and technological achievement score, both normalized on a 0–1 scale, see Fig. 7. This was done according to $M-(1-N)$ for the comparison to the fulfilling of basic human needs and $M-(1-T)$ for the comparison to technological achievement. Figure 7 represents the comparison between aid dollars and the fulfilling of basic human needs, and Fig. 8 represents the comparison between aid dollars and technological achievement. Countries in yellow represent an alignment of aid dollars to the assessment of the model. Green countries are receiving more aid per capita than may be reasonably expected based on the assessment of the model. Red countries are receiving less aid per capita than may be reasonably expected based on the assessment of the model and may deserve more attention by the EGD community. Countries receiving less than one dollar per person were excluded from the figure. This indicates that there is opportunity for the EGD community to more closely examine where work is performed to have a potential for greater social impact with limited resources.

Table 4 Uganda, India, Brazil, and United States result summary

Country	Basic human need	Technological achievement	Work environment
Brazil	0.79	0.36	0.49
India	0.54	0.33	0.67
Uganda	0.30	0.20	0.44
United States	0.97	1.00	0.90

5 Conclusions

With the growth of the EGD community, it is important that there are models available to help guide practitioners to potential locations for EGD projects. These models are not just for new projects, but they also help us understand if there are similar places we may be able to expand current projects to. While all relevant indicators from the sources described were included in the model, there are still limitations and assumptions inherent in this model, including (i) the lack of data from the reliable sources used in this article for how unrest affects the work environment in a country and (ii) that the data are aggregated at the country level, thus obscuring regional needs. Despite the limitations, the use of quantitative tools such as these models are valuable when selecting potential project locations. The nuanced nature of project selection will require the use of quantitative and qualitative methods to make project selection choices.

When undertaking projects with limited resources, it becomes vital that the question of where to work is considered in a logical approach using quantitative and qualitative methods. These quantitative models of *basic human needs*, *technological achievement*, and *work environment* along with qualitative elements such as design team competencies or potential partners will help guide members of the EGD community to make more informed decisions about where in the world engineering projects should be undertaken.

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Conflict of Interest

There are no conflicts of interest.

Data Availability Statement

Data will be available for download at https://www.design.byu.edu/resources. The authors attest that all data for this study are included in the paper. Data provided by a third party listed in Acknowledgment.

Nomenclature

M = foreign aid dollars per capita
N = basic human need score
T = technological achievement score
W = work environment in a country
s_{ij} = normalized score for country i and indicator j
N_A = existence need score
N_{A1} = access to clean fuels and technologies for cooking (% of population)
N_{A2} = access to electricity (% of population)
N_{A3} = adolescent fertility rate (births per 1,000 women ages 15–19)
N_{A4} = annual freshwater withdrawals, total (% of internal resources)
N_{A5} = arable land (hectares per person)
N_{A6} = births attended by skilled health staff (% of total)
N_{A7} = cause of death, by communicable diseases and maternal, prenatal and nutrition conditions (% of total)
N_{A8} = cause of death, by injury (% of total)
N_{A9} = cause of death, by noncommunicable diseases (% of total)
N_{A10} = cereal yield (kg per hectare)
N_{A11} = contraceptive prevalence, any methods (% of women ages 15–49)
N_{A12} = contraceptive prevalence, modern methods (% of women ages 15–49)
N_{A13} = contributing family workers, total (% of total employment) (modeled ILO estimate)
N_{A14} = crop production index $(2004-2006=100)$
N_{A15} = death rate, crude (per 1,000 people)
N_{A16} = diabetes prevalence (% of population ages 20–79)
N_{A17} = droughts, floods, extreme temperatures (% of population, average 1990–2009)
N_{A18} = employment to population ratio, 15+, total (%) (modeled ILO estimate)
N_{A19} = employment to population ratio, ages 15–24, total (%) (modeled ILO estimate)
N_{A20} = fertility rate, total (births per woman)
N_{A21} = food production index (2004–2006 = 100)
N_{A22} = GDP per capita, PPP (constant 2011 international $)
N_{A23} = GNI per capita, PPP (constant 2011 international $)
N_{A24} = immunization, DPT (% of children ages 12–23 months)
N_{A25} = immunization, HepB3 (% of one-year-old children)
N_{A26} = immunization, measles (% of children ages 12-23 months)
N_{A27} = incidence of tuberculosis (per 100,000 people)
N_{A28} = intentional homicides (per 100,000 people)
N_{A29} = labor force participation rate for ages 15–24, total (%) (modeled ILO estimate)
N_{A30} = labor force participation rate, total (% of total population ages 15+) (modeled ILO estimate)
N_{A31} = level of water stress: freshwater withdrawal as a proportion of available freshwater resources
N_{A32} = life expectancy at birth, total (years)
N_{A33} = lifetime risk of maternal death (%)
N_{A34} = maternal mortality ratio (modeled estimate, per 100,000 live births)
N_{A35} = mortality caused by road traffic injury (per 100,000 people)
N_{A36} = mortality from CVD, cancer, diabetes, or CRD between exact ages 30 and 70 (%)
N_{A37} = mortality rate attributed to household and ambient air pollution, age-standardized (per 100,000 population)
N_{A38} = mortality rate attributed to unintentional poisoning (per 100,000 population)
N_{A39} = mortality rate attributed to unsafe water, unsafe sanitation, and lack of hygiene (per 100,000 population)
N_{A40} = mortality rate, infant (per 1,000 live births)
N_{A41} = mortality rate, neonatal (per 1,000 live births)
N_{A42} = mortality rate, under 5 (per 1,000 live births)
N_{A43} = nitrous oxide emissions (% change from 1990)
N_{A44} = nurses and midwives (per 1,000 people)
N_{A45} = people practicing open defecation (% of population)
N_{A46} = people using at least basic drinking water services (% of population)
N_{A47} = people using at least basic sanitation services (% of population)
N_{A48} = personal transfers, receipts (BoP, current US$)
N_{A49} = physicians (per 1,000 people)
N_{A50} = PM2.5 air pollution, mean annual exposure (micrograms per cubic meter)
N_{A51} = poverty gap at $1.90 a day (2011 PPP) (%)
N_{A52} = poverty gap at $3.20 a day (2011 PPP) (%)
N_{A53} = poverty gap at $5.50 a day (2011 PPP) (%)
N_{A54} = poverty headcount ratio at $1.90 a day (2011 PPP) (% of population)
N_{A55} = poverty headcount ratio at $3.20 a day (2011 PPP) (% of population)
N_{A56} = poverty headcount ratio at $5.50 a day (2011 PPP) (% of population)
N_{A57} = prevalence of anemia among children (% of children under 5)
N_{A58} = prevalence of anemia among non-pregnant women (% of women ages 15–49)

N_{A59} = prevalence of anemia among pregnant women (%)
N_{A60} = prevalence of undernourishment (% of population)
N_{A61} = primary income payments (BoP, current US$)
N_{A62} = probability of dying at age 5–14 years (per 1,000 children age 5)
N_{A63} = pump price for diesel fuel (US $ per liter)
N_B = relatedness need score
N_{B1} = adolescent fertility rate (births per 1,000 women ages 15–19)
N_{B2} = adolescents out of school (% of lower secondary school age)
N_{B3} = age dependency ratio, old (% of working-age population)
N_{B4} = children out of school (% of primary school age)
N_{B5} = compulsory education, duration (years)
N_{B6} = contraceptive prevalence, any methods (% of women ages 15–49)
N_{B7} = contraceptive prevalence, modern methods (% of women ages 15–49)
N_{B8} = educational attainment, at least completed lower secondary, population 25+, total (%) (cumulative)
N_{B9} = educational attainment, at least completed postsecondary, population 25+, total (%) (cumulative)
N_{B10} = fixed broadband subscriptions (per 100 people)
N_{B11} = fixed telephone subscriptions (per 100 people)
N_{B12} = individuals using the Internet (% of population)
N_{B13} = literacy rate, adult total (% of people ages 15 and above)
N_{B14} = lower secondary completion rate, total (% of relevant age group)
N_{B15} = mobile cellular subscriptions (per 100 people)
N_{B16} = overage students, primary (% of enrollment)
N_{B17} = persistence to grade 5, total (% of cohort)
N_{B18} = persistence to last grade of primary, total (% of cohort)
N_{B19} = preprimary education, duration (years)
N_{B20} = primary completion rate, total (% of relevant age group)
N_{B21} = primary education, duration (years)
N_{B22} = progression to secondary school (%)
N_{B23} = pupil–teacher ratio, lower secondary
N_{B24} = pupil–teacher ratio, preprimary
N_{B25} = pupil–teacher ratio, primary
N_{B26} = pupil–teacher ratio, secondary
N_{B27} = pupil–teacher ratio, tertiary
N_{B28} = pupil–teacher ratio, upper secondary
N_{B29} = repeaters, primary, total (% of total enrollment)
N_{B30} = school enrollment, preprimary (% gross)
N_{B31} = school enrollment, primary (% gross)
N_{B32} = school enrollment, secondary (% gross)
N_{B33} = school enrollment, secondary (gross), gender parity index (GPI)
N_{B34} = school enrollment, secondary, private (% of total secondary)
N_{B35} = school enrollment, tertiary (% gross)
N_{B36} = secondary education, duration (years)
N_C = growth need score
N_{C1} = access to electricity (% of population)
N_{C2} = adolescents out of school (% of lower secondary school age)
N_{C3} = charges for the use of intellectual property, payments (BoP, current US $)
N_{C4} = children out of school (% of primary school age)
N_{C5} = compulsory education, duration (years)
N_{C6} = cost of business start-up procedures (% of GNI per capita)
N_{C7} = ease of doing business score (0 = lowest performance to 100 = best performance)
N_{C8} = educational attainment, at least completed lower secondary, population 25+, total (%) (cumulative)
N_{C9} = educational attainment, at least completed post-secondary, population 25+, total (%) (cumulative)
N_{C10} = employers, total (% of total employment) (modeled ILO estimate)
N_{C11} = individuals using the Internet (% of population)
N_{C12} = internally displaced persons, new displacement associated with disasters (number of cases)
N_{C13} = literacy rate, adult total (% of people ages 15 and above)
N_{C14} = lower secondary completion rate, total (% of relevant age group)
N_{C15} = persistence to grade 5, total (% of cohort)
N_{C16} = persistence to last grade of primary, total (% of cohort)
N_{C17} = poverty gap at $1.90 a day (2011 PPP) (%)
N_{C18} = poverty headcount ratio at $1.90 a day (2011 PPP) (% of population)
N_{C19} = poverty headcount ratio at $3.20 a day (2011 PPP) (% of population)
N_{C20} = poverty headcount ratio at $5.50 a day (2011 PPP) (% of population)
N_{C21} = primary completion rate, total (% of relevant age group)
N_{C22} = private credit bureau coverage (% of adults)
N_{C23} = progression to secondary school (%)
N_{C24} = proportion of seats held by women in national parliaments (%)
N_{C25} = pupil–teacher ratio, lower secondary
N_{C26} = pupil–teacher ratio, preprimary
N_{C27} = pupil–teacher ratio, primary
N_{C28} = pupil–teacher ratio, secondary
N_{C29} = pupil–teacher ratio, upper secondary
N_{C30} = repeaters, primary, total (% of total enrollment)
N_{C31} = school enrollment, preprimary (% gross)
N_{C32} = school enrollment, primary (% gross)
N_{C33} = school enrollment, secondary (% gross)
N_{C34} = school enrollment, tertiary (% gross)
N_{C35} = self-employed, total (% of total employment) (modeled ILO estimate)
N_{C36} = time required to start a business (days)
N_{C37} = unemployment with advanced education (% of total labor force with advanced education)
N_{C38} = unemployment with basic education (% of total labor force with basic education)
N_{C39} = unemployment with intermediate education (% of total labor force with intermediate education)
N_{C40} = unemployment, total (% of total labor force) (modeled ILO estimate)
N_{C41} = vulnerable employment, total (% of total employment) (modeled ILO estimate)
S_{ij} = value for country i and indicator j
T_A = scientific innovation and invention score
T_{A1} = number of scientific and technical journal articles
T_{A2} = number of patents granted
T_B = penetration of older technologies
T_{B1} = electrical power consumption
T_{B2} = air transport, registered carrier departures
T_{B3} = agricultural machinery
T_{B4} = exports of manufactures
T_C = penetration of recent technologies
T_{C1} = high-technology exports
T_{C2} = percent of population using the internet
T_{C3} = cellular subscriptions
T_{C4} = cellular network coverage
T_D = exposure to external technology
T_{D1} = FDI net inflow
T_{D2} = royalties and license fee payments
T_{D3} = high-technology imports
T_{D4} = capital goods imports
T_{D5} = intermediary goods imports
W_1 = ease of doing business score
W_2 = incidence of corruption
W_3 = openness to foreigners
W_4 = business environment
W_5 = air transport infrastructure
W_6 = ground and port infrastructure

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