STRUCTURAL EQUATIONS MODELING TO TEST IMPACTS OF SUSTAINABILITY INDICATORS TO PRICE AND REVENUE IN WAYANG WINDU GEOTHERMAL FIELD, INDONESIA

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ABSTRACT

Sustainable geothermal operations refers to such energy that will be produced and used in such a way that it is compatible with the well-being of current and future generations. The general objective of this study is to identify and assess a *simple set of business sustainability indicators that may enhance integrated (direct-indirect) utilization of geothermal energy generation addressing social, environmental as well as business issues*. Some selected project parameters or business indicators were actual secondary data acquired from existing geothermal operations and projects in Pangalengan village, West Java. The geothermal producing field had for many years proven itself to maintain GOLD rating in environmental and social responsibility achievements from the State Ministry of Environment.

Structural Equations Modeling (SEM) is a family of statistical models that seek to explain the relationship among multiple variables. In doing so, it examines the structure of interrelationships expressed in a series of equations, similar to a series of multiple regression equations. Theory must be the foundation of even the simplest of models; because variables may always be linked to one nother in multiple ways.

A basic correlational selection of business or economic indicators, ecological or environmental indicators and social or socio-cultural indicators has resulted in a need to test relationship hypotheses of indicators of Local Involvement to Projects (social / socio-cultural), Biodiversity, Recharging or reinjection of brines and condensates and Emission of Greenhouse Gases (ecological) in addition to Reservoir Pressure (Business) – as independent variables impacting Actual Energy Pricing – as a dependent variable. The SEM model clearly shows that business, economics, ecological, environmental and social or socio-cultural indicators are instrumental in establishing a sustainable equilibrium in both direct and indirect geothermal resources utilization.

GEOTHERMAL SUSTAINABILITY

The products of modern geothermal business are **heat** and/or **hot steam** to move turbines that generate electricity (as indirect use for energy) and for domestic purposes (i.e. heating, washing, bathing etc.) as direct uses. **DiPippo (2008)** and **Grant & Bixley (2011)** defined the *geothermal reservoir* as the underground section of the geothermal field that is so *hot and permeable that it can be economically exploited for the production of fluid or heat*. Such section is only a part of the field or hot rock and fluids underground. Hot rocks that are impermeable are not part of the reservoir.

The original definition of sustainable development goes back to the Brundtland Commission Report (1987; reinforced at the Rio 1991 and Kyoto 1997 Summits):

“Development that meets the needs of the present without compromising the ability of future generations to meet their own needs”.

As shown in Figure 1, sustainable development practically meets the requirements of

1. ‘bearable’ area overlapping ‘planet-people’ (environment – social) interests,
2. ‘viable’ area overlapping ‘planet-profit’ (environment-business) interests,
3. ‘Equitable’ area overlapping ‘profit-people’ (business-social) interests.

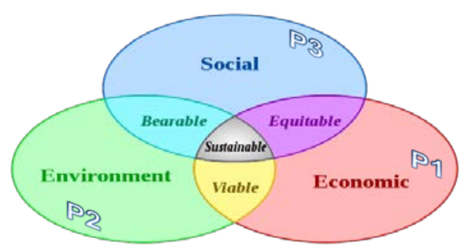

Figure 1: Illustration of Basic Sustainability Model (Bruntland, 1987)

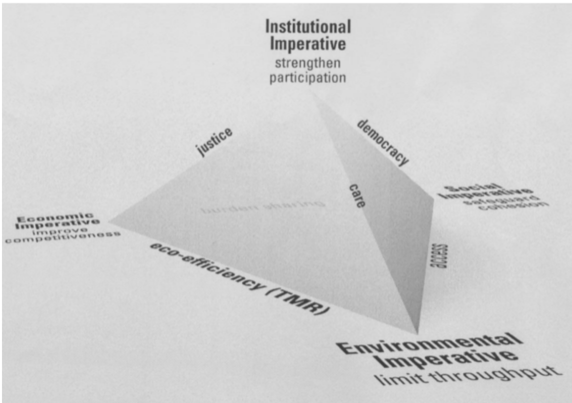

Figure 2: Four-dimensional Sustainability Model

Spangenberg et.al (2000) of the Wuppertal Institute had since 1997 proposed the four-dimensional prism of sustainability. The model defines sustainability as consisting of four dimensions—the social, economic, environmental, and institutional ones—as it is shown by the *Prism of Sustainability* in Fig 2. Institution is meant here to be defined as in the political science, including not only organizations, but also mechanisms and orientations, etc. The Prism of Sustainability corresponds, for example, to Serageldin's economic terminology of man-made, natural, social, and human capital. The social dimension (human capital) refers to the aggregate of human capabilities, whereas the institutional dimension (confusingly called the social capital) refers to human interaction and the rules by which they are guided, i.e., to the institutions of the society. **Spangenberg et.al (2000)** had linked these dimensions to imperatives—ultimately, the definition of Sustainable Development is nothing but the application of the Kantian "Categorical Imperative" to lifestyle and environmental issues. Indicators presented by Spangenberg et.al. are the result of a number of pilot processes, involving a variety of societal groups and scientific disciplines.The proposed imperatives only define themes of sustainable development. Each organization or a productive community has to develop its individual set of indicators within this common structure.

The Institute for Global Environmental Strategies in Kanagawa, Japan (**IGES, 2010**) re-iterated the definition of Sustainable Consumption and Sustainable Production as follows:

- Sustainable consumption is the use of services and related products which respond to basic needs and bring a better quality of life while minimizing the use of natural resources and toxic materials as well as emissions of waste and pollutants over the life-cycle so as not to jeopardize the needs of future generations (**UNEP, 2010**).
- Sustainable production is the creation of goods and services using processes and systems that are non-polluting, conserving energy and natural resources, are economically efficient, are safe and healthy for workers, communities and consumers; and are socially and creatively rewarding for all working personnel (**LCSP/Lowell Center for Sustainable Production, 2009**).

In relation to geothermal resources and, especially, to their exploitation, sustainability means *the ability of the production system applied to sustain the production level over long times.* Sustainable production of geothermal energy therefore secures the longevity of the resource, at an appropriate production level.

A practical definition of sustainable production from a geothermal system has been suggested recently for academic and technical purpose (**Axelsson, et al., 2001**):

"For each geothermal system, and for each mode of production, there exists a certain level of maximum energy production, below which it will be possible to maintain constant energy production from the system for a very long time (100 – 300 years)."

This (technical) definition applies to the total extractable energy (the heat in the fluid plus that in the rock), and depends on the nature of the system, but not on load factors or utilization efficiency. The definition does not consider economic aspects, environmental issues or social and technological advances, all of which may be expected to change with time. The terms renewable and sustainable are often confused, and it is important to stress that the former concerns the nature of a resource and the latter applies to how a resource is managed and utilized (**Axelsson, et al., 2002**).

Grant and Bixley (2011) described most areas with geothermal activity, provided they are distinct and separate from neighboring areas of activity, as *geothermal fields.* The term is intended to be purely a convenient geographic description and makes no presumption about the greater *geothermal system* that has created and maintains the field activity. The many geothermal fields in the world with double names – such as Mak-Ban (Makiling-Banahaw), Karaha-Bodas (KB), Bac-Man (Bacon-Manito), Wayang-Windu (WW), etc.- illustrate how exploration has shown that surface activity originally thought to be associated with separate fields is later found to be part of a single, larger field. The total subsurface hydrologic system associated with a geothermal field is termed a *geothermal system*. This includes all parts of the flow path, from the original cold source water, its path down to a heat source, and finally its path back up to the surface.

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SUSTAINABILITY INDICATORS

Various literature sources define indicators as tools to "simplify, measure and communicate trends and events" (**Eckersley, 1997**) or as "*quantitative measures that can illustrate and communicate complex phenomena simply, including trends and progress over time*" (**EEA, 2005**). Indicators may be considered as *valuable policy tools for measurement and evaluation of transport sustainability performance*. During the last two decades, measurement of sustainability issues by indicators has been widely used by the scientific community and policy-makers. Development of sustainable development indicators was first brought up as a political agenda issue at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro in 1992. The UNCED policy declaration Agenda 21 requested countries at the national level and international governmental and non-governmental organizations at the international level to develop indicators in the context of improving information for decision making (**United Nations, 1992**, Chapter 40). Since then, indicators are thought to be important tools for measurement of different aspects of sustainable development, including energy related issues.

Indicators reflect society's values and goals and become key drivers of change. They help to measure and understand directions of progress (**Henderson, 1996**). Other literature sources similarly define indicators as statistics designed to allow significant trends to be monitored (**Gilbert & Tanguay, 2000**). **Litman (2007)** in his paper on developing indicators for comprehensive and sustainable transport planning states that "*indicators are things we measure to evaluate progress towards goals and objectives*". They may have several functions, such as helping to identify trends, predict problems, assess options, set performance targets, and to evaluate a particular jurisdiction or organization.

The following presents some techno-economical *indicators that are found* practical for use with assessing sustainability criteria (**Rybach & Mongillo, 2009**): 1)"Balanced" fluid/heat production that does not exceed the recharge can be considered fully sustainable. 2) Production rates that persistently exceed the rate of recharge (natural or induced) will eventually lead to reservoir depletion, thus stopping **economic** production 3) Post exploitation recovery typically exhibits an asymptotic behavior, being strong at the start and slowing subsequently, and reaching a "practical" replenishment (~95% recovery) on time scales of the same order as the lifetime of the geothermal production system. 4) Geothermal resources are renewable on timescales of technological/societal systems (~30-300 years). 5) The level of sustainable production depends on the utilization technology as well as on the geothermal resource characteristics and 6) Long-term economic production from geothermal resources should be limited to sustainable levels. **Darwin et.al.** in **GRI (2006)** had attempted to compile and formulate for the Indonesia's National Center for Sustainability Reporting (NCSR) some applicable performance indicators as shown in Table (2-5). The practical compilation was based on a series of international work undertaken by the Expert Group on Indicators of Sustainable Development (UNISD). The initial work on energy indicators was developed throughout the years with the UN Commission on Sustainable Development (UN-CSD) then the World Summit on Sustainable Development (WSSD) with the UN-CSD and the UN Department of Economics and Social Affairs (UNDESA) in 2004-2005. The core set of energy indicators, now called 'Energy Indicators for Sustainable Development' (EISD), has been designed to provide information on current energy-related trends in a format that aids decision making at the national level in order to help countries assess effective energy policies for action on sustainable development.

Table 1: Generic Sustainability Indicators (GRI, 2006)

	Category	Aspect
Economic	Direct Economic Impacts	Customers Suppliers Employees Providers of capital Public sector
Environmental	Environmental	Materials Energy Water Biodiversity Emissions, effluents, and waste Suppliers Products and services Compliance Transport Overall
Social	Labour Practices and Decent Work	Employment Labour/management relations Health and safety Training and education Diversity and opportunity
	Human Rights	Strategy and management Non-discrimination Freedom of association and collective bargaining Child labour Forced and compulsory labour Disciplinary practices Security practices Indigenous rights
	Society	Community Bribery and corruption Political contributions Competition and pricing
	Product Responsibility	Customer health and safety Products and services Advertising Respect for privacy

Whilst agencies such as International Atomic Energy Agency (IAEA) and International Energy Agency (IEA) have been very active in formulating further work on EISD, the global energy organizations such as the World Petroleum Congress and the World Geothermal Association have never initiated any similar EISD effort in such a more comprehensive way.

CONCEPTUAL FRAMEWORK

Theoretical background as shown in Appendix 1 will have to support and justify a need to test relationship hypotheses of indicators of LIP (social / society), BIO, REC and GHG (ecological) and PRES (Business) impacting PRICE. As shown in Figure (3-4) above, AMOS version of SEM is able to calculate coefficients of correlations (left networking) and linear regression (right networks). **Hitzhousen et.al (2009)** noted such supply-demand equilibrium shown in Appendix-1 has incorporated all indicators pertaining to social aspects; such as Corporate Social Responsibility (CSR) and role of local contractors, or in our case it is represented by the Local Involvement to Project (LIP).

Hypothesis #1 : Impact of a Social Indicator P3 (LIP: Local Involvement to Project) to Price of Electricity.

- Ho = relationship of LIP with PRC are insignificant
- H_1 = there is a significance in such relationship.

Energy Price for a producer has been set to fulfill three criteria: Long-run Marginal Cost (LRMC), recovery premium and externalities. **Yusgiantoro (2000)** suggested to approach using the LRMC values with a discreet function of Average Incremental Cost (AIC). AIC, which is commonly utilized by World Bank, Asian Development Bank, OECD etc., is a function of mainly cost of capital plus operating and maintenance costs. Recovery Premium is applicable only for non-renewable energy such as fossil-fuels (oil, gas, coal). For renewable energy such as geothermal, this premium is reflected by series of proper recharging (REC) activities to secure both pressure maintenance and equilibrium of materials and inertia replacement (hydrological cycle).

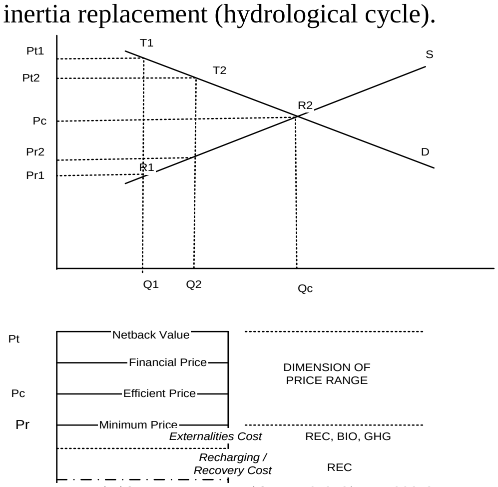

*Figure 2: Range of Energy Pricing in Indonesia (**Yusgiantoro, 2000**)*

As shown in Figure 2, among other ecological and social indicators, Biodiversity (BIO), Recharging (REC), 'Emission of Green House Gases (GHG) and Local Involvement into Project (LIP) are part of the Average Incremental Cost (AIC) and Cost of Externalities. Theoretically, henceforth, all such independent indicators have impact or contains some relationship to the dependent variable of energy price (PRC). These may be illustrated in the structural equations model as shown in Figure 3.

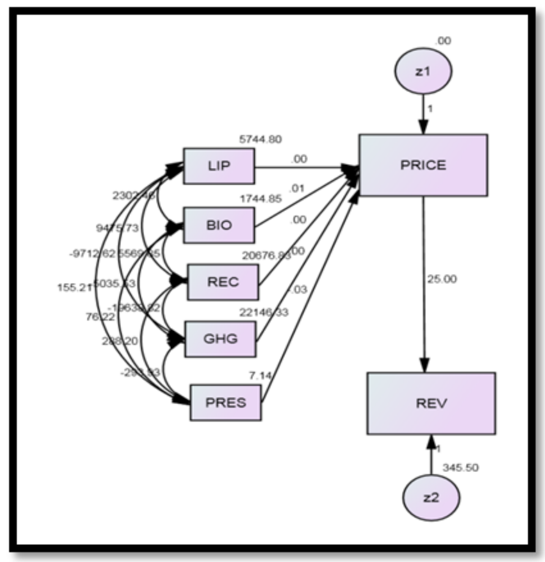

Figure 3: Proposed SEM Modeling

Concurrent with above arguments, the following hypotheses may therefore be proposed:

Hypothesis #2 : Impact of P2(BIO:biodiversity) to Price of Electricity.

- H_0: Linear modeling of BIO vs. PRC will occur insignificantly.
- H2: Linear modeling of BIO vs. PRC will be significant.

Taking an analogous condition from the Geysers (Figure 4), where extensive decline curve during late 1980s throughout mid 1990s is significantly halted through intensive injection, a recharging (REC) indicator may be proposed to impact economic indicators such as price (PRC) and revenue (REV).

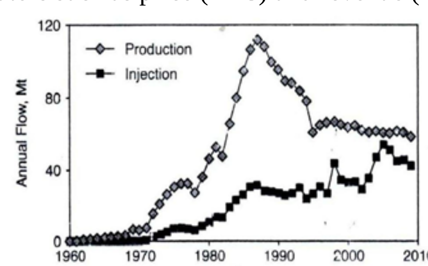

*Figure 4: Steam Production and Injection at the Geysers, California (**Grant & Bixley, 2011**)*

Hypothesis #3 : P2(Ecological Indicator: REC:recharging) to Electricity Price.

- H_0: Linear modeling of REC vs. PRC will sound insignificantly.
- H_3: Linear modeling of REC vs. PRC will be significant.

Hypothesis #4 : P2(Ecological/Environmental Indicator: GHG:greenhouse gas) vs.PRC

- H_0: Linear modeling of GHG vs. PRC will sound insignificantly
- H_4: Linear modeling of GHG vs. PRC will be significant.

Mulyadi and Smillie (2012) confirmed that Flow rate and Liquid and Stem Pressure Declines in the Wayang Windu geothermal wells would represent the main key sustainability indicators with overall objectives to assess profitability and viability of this geothermal energy project. With a calculated (in a reservoir modeling simulation) natural decline of 9%/annum, a 14-16%/annum decline shown from this well's flow rate was detected and after immediately remedying the wells with acidizing treatment (simply to clean up the reservoir), a gain of 14 kilogram /second flow rate was tested. A further elaboration of applying this leading indicator is illustrated in Figures 5. The models shown in the linear regression equations will be useful to assess the field's production sustainability. This research indicates an actual decline of 14%/annum as opposed to the simulated natural decline of 9%/annum; which warrants some immediate field corrective actions (such as well clean up; acidizing etc.). After such a treatment, the rate improves back to its natural decline at 9% (Figure 5).

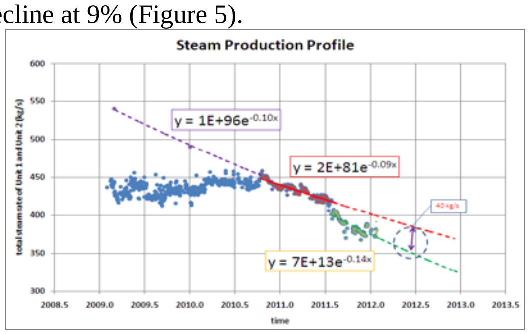

*Figure 5: Field Wide Steam Production Profile (**Smillie, 2012**)*

The steam supply in the Wayang Windu case study shown in Figure 6; in reality as plotted out from actual measurement in the field (figure 5), does really meet 'history matching principles'. A composite model shown in Figure 7 justifies extension of such 'geoscientific'model into a three-dimensional economics-ecological-social model. Theoretical statements for PRES (reservoir pressure) indicator having impact to COST and PRICE indicators may likely be having significant relationship. Concurrent with above arguments, the following hypothesis is proposed:

Hypothesis #5 : P1 (Economic Indicator PRES:reservoir pressure) vs. PRICE

- H_0: Linear modeling of PRES vs. PRC will sound insignificantly
- H_5: Linear modeling of PRES vs. PRC will be significant.

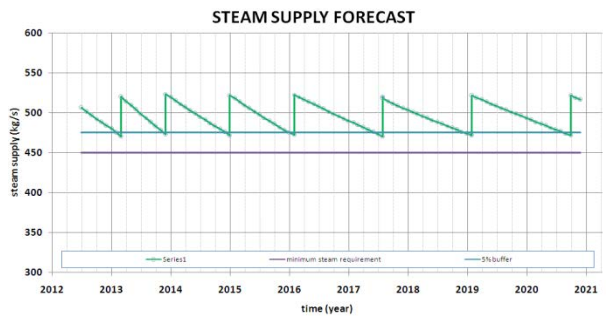

*Figure 6: Steam Supply Forecast from Reservoir Modeling (**Smillie, 2012**)*

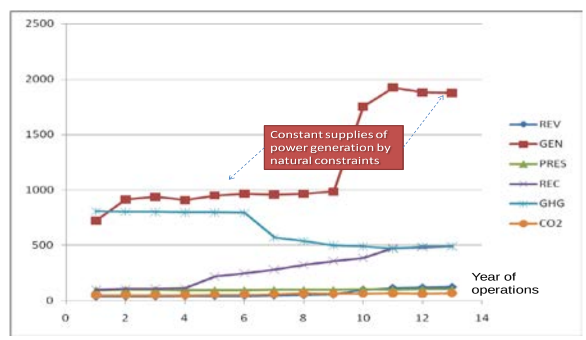

Figure 7: Composite Performance of the Field

RESULTS OF MODELING

The correlation numbers shown at left networks in the model depicted above should not be considered meaningful unless they show how positively or negatively those LIP, BIO, REC, GHG and PRES indicators are correlated among each other.

Testing Goodness of Fit

In the SEM, the goodness of fit of the model may utilize various approaches.

Hypothesis:

H_o : Empirical data is no identical to the theory/model

H_a : Empirical data is identical and may not differ from theory/model

Testing of (goodness-of-fit model may use several criteria of measures, namely: chi-square, Goodness-of Fit Index (GFI), Root Mean Square Error of approximation (RMSEA), Adjusted Goodness-of Fit Index (AGFI), Tucker-Lewis-Index (TLI), Comparative Fit Index (CFI), Normed Chi-square (CMIN/df).

Absolute Fit Measures

Absolute Fit Measures, cover the overall model fit (either structural or simultaneous model). The criterion looks into the values of:

The Likehood-Ratio Chi Square Statistics

Minimum significance level of 0.05 and 0.01 at measurement of *chi-square* is acceptable. We look for a non-signifikan difference because this test is spotted within actual and predictive matrix.Measurement of *chi-square* are subject to the number of samples, therefore some previous research workers suggested to incorporate this measure into other measurements (**Hair et al., 2006**).

1. Goodness-Fit Index (GFI)

The higher value of GFI, its model gets more fit. No standard of values emerge as a reference. However, some researchers have recommended a GFI value of 0.90 or more.

2. The Root Mean Square Error of Approximation (RMSEA)

RMSEA is an index to compensate *chi-square statistics* in a large sample. RMSEA resembles *goodness-of-fit* as expected if a model is estimated in population. RMSEA can be functional if *chi-square* values are significant. Value that is needed to make RMSEA is considered fit is < 0,08(**Hair et al.,2006**).

Incremental Fit Measures

Incremental Fit Measures, represents a yardstick that compares *proposed model*) with another specified by the researcher. The criteria will cover the following:

1. *Normed Fit Index* (NFI)

Suggested value ranges from 0.90 or closer to 1

2. *Adjusted Goodness of Fit Index* (AGFI)

Suggested value of AGFI equals or more than 0.90

3. *Tucker-Lewis Index* (LTI)

Suggested value ranges from 0.90 or closer to 1

4. *Comparative Fit Index* (CFI)

Suggested value ranges from 0.90 or closer to 1

Parsimonious Fit Measures

Parsimonious Fit Measures, includes promoting adjustment to fit measures for inter-model comparison with number of coefficients from the lower limit of 1 to the upper limit of 5. To analyze data, the method to use is to test hypothesis in various layers. We use a criterion of value of *Normed Chi-Square* (CMIN/DF) with a confidence level of 95% (α = 0,05). Results of using criteria for some indicators of goodness of fit may be shown in table 2.

From Table 2, despite measures show poorly fit, at least NFI and CFI demonstrate a model fit, which leads us to justify for accepting theoretical hypothesis to continue on.

From Table 3, on the basis of test using AMOS version 18.00 programs, the following will be disclosed to address alternative hypothesis#1.

Table 2: Criteria of Goodness of Fit

Goodness of fit index	Criterion (cut-off value)	Values	Remarks
Chi-Square (X^2)	Approaching 0	35,685	Poorly Fit
Probability	≥ 0,05	0,000	Poorly Fit
RMR	< 0,10	127,376	Poorly Fit
NFI	**Approaching 1**	**0,816**	**Goodness of Fit**
CFI	**Approaching 1**	**0,822**	**Goodness of Fit**
RMSEA	< 0,10	0,715	Poorly Fit

Table 3: Test of Hypotheses

H_0 = There exists no impact of PI/P2/P3 indicators towards PRICE	Coefficient */(SPSS Values)*	Proba-bility	Concluding Remarks
H_1 = There exists an impact of LIP towards PRICE	-0,001/-*0,002*	0,034	H_0 fails off – rejected *H_1* is accepted
H_2 = There exists an impact of BID towards PRICE	0,010/*0,007*	0,000	H_0 fails off - rejected *H_2* is accepted
H_3 = There exists an impact of REC towards PRICE	0,003/*0,005*	0,000	H_0 fails off - rejected *H_3* is accepted
H_4 = There exists an impact of GHG towardsPRICE	-0,003/*-0,007*	0,000	H_0 fails off – rejected *H_4* is accepted
H_5 = There exists an impact of PRES toerds PRICE	-0,028/*n.a*	0,023	H_0 fails off – rejected *H_5* is accepted
H_6 = There exists an impact of PRICE towards REV	25,001/*25,053*	0,000	H_0 fails off – rejected *H_6* is accepted

The magnitude of Coefficient of *LIP* is -0.001 (SPSS Coefficient value shows -0,002) which means that if *LIP* increases by one USD thence *PRICE* will decrease at 0.001 USD cent/kWh. Statistical test shows that p-value equals 0,034 which is < 0.05 (alpha 5%) therefore alternative 1 hypothesis fails off and is to be rejected. In conclusion, at the confidence level of 95%, there exists an impact of negative *LIP* to *PRICE*. This may sound expectedly questionable. However with the empirical fact that only the lowermost level of local employees and smallest rank of local contractors qualify and contribute in the project, this direction of impact is really not unexpected.

To address alternative hypothesis#2, we look at the magnitude of coefficient of *BIO* equals 0.010; which means if *BIO* increases by one unit then *PRICE* will increase by 0.010 USD cent/kWh. Result of statistical test shows p-value equals 0.000 < 0.05 (alpha 5%) thus alternative hypothesis#2 fails and is rejected. As a conclusion, statistically at a level of confidence of 95% there exists a positive impact of *BIO* towards *PRICE*.

To address alternative hypothesis #3, we check the magnitude of coefficient of *REC* equals 0.003; which means that if *REC* increases by one unit then *PRICE* will increase by 0.003 USD cent/kWh. Result of statistical test shows p-value equals 0,000 < 0.05 (alpha 5%) thus alternative hypothesis#3 fails and to be rejected. As a conclusion, statistically at a level of confidence of 95% there exists a positive impact of *REC* towards *PRICE*.

To address alternative hypothesis#4, we look at the magnitude of coefficient of *GHG* equals -0.003; which means if *GHG* increases by one unit then *PRICE* will decrease by 0.003 USD cent/kWh. Result of statistical test shows p-value equals 0,034 < 0,05 (alpha 5%) thus alternative hypothesis#4 fails and is rejected. As a conclusion, statistically at a level of confidence of 95% there exists a negative impact of *GHG* towards *PRICE*.

To address alternative hypothesis#5, we check the magnitude of coefficient of *PRES* equals -0.028; which means if *PRES* increases by one bar-absolute then *PRICE* will decrease by 0.028 USD cent/kWh. Result of statistical test shows p-value equals 0.023 < 0.05 (alpha 5%) thus alternative hypothesis#5 fails and is rejected. As a conclusion, statistically at a level of confidence of 95% there exists a negative impact of *PRES* towards *PRICE*.

From table (4-3), on the basis of test using AMOS version 18.00 program, the magnitude of Coefficient of *PRC* is 25.001 which means that if *PRC* increases by one USD cent/kWh thence *REV* will increase at 25.001 millions of USD. Statistical test shows that p-value equals 0.000 which is < 0.05 (alpha 5%)

therefore alternative 6 hypothesis fails off and is to be rejected. In conclusion, at the confidence level of 95%, there emerges a positive impact of negative *PRICE* to *REVENUE*. This finding just expectedly sounds in the right direction.

Recalling that regression coefficients can be used to compute predicted values for dependent variables, those values are referred to as ¥ or "y-cap". Thus in our model, if we take any observed values for all indicators, we can estimate the values of Price and Revenue Caps using the following equations:

$$¥_{PRICE} = \beta_o + 0,001\ LIP + 0,010\ BIO + 0,013\ REC - 0,003\ GHG - 0,0025\ PRES \text{.....................(Eq.1)}$$

$$¥_{REV} = \beta_o + 25\ PRICE + \varepsilon \text{.................(Eq.2)}$$

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APPENDIX 1
(attached on a separate sheet)

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