



WP/ 2 /2020

WORKING PAPER

**SOVEREIGN GREEN SUKUK: ENVIRONMENTAL RISK
MODEL DEVELOPMENT**

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2020

Kesimpulan, pendapat, dan pandangan yang disampaikan oleh penulis dalam Laporan Hasil Penelitian ini merupakan kesimpulan, pendapat, dan pandangan penulis dan bukan merupakan kesimpulan, pendapat, dan pandangan resmi Bank Indonesia.

SOVEREIGN GREEN SUKUK: ENVIRONMENTAL RISK MODEL DEVELOPMENT

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Abstract

Green Sukuk continues to grow, but it still has problems in pricing. It has an unexplainable pricing difference between Green and Non-Green financing instruments. The research selects to take a fundamental asset pricing methodology that analyzes environmental risk. Sukuk and other financings might finance environmentally-harmful projects which support waste generation and accumulation. We noticed that unique environmental risks impose Sukuk holders, i.e., systemic and reputation risks. Finally, the model confirmed that these risks cause the price difference.

Key words: Islamic finance, Climate risk, Climate finance, Environmental systemic risk premium, Environmental Reputation Risk Premium

JEL Classification: F64, G12, Q51, Q54, L14

1. INTRODUCTION

1.1 Background

The Accounting and Auditing Organization for Islamic Financial Institutions (AAOIFI) defines a Sukuk as a proof of ownership, such as undivided shares with ownership of specific project assets or specific investment activities. AAOIFI exposes Standard No.17 on Investment Sukuk to govern Sukuk's types (Saeed and Salah, 2014). The contractual right may extend it to the right held in trust for Sukuk holders. Safari and Ariff (2013) found that Sukuk was a finite-life and share-like securities.

Like equity price, Sukuk price varies with the firm's risk, which draws portfolio managers' attention and has three reasons. The first reason, Cakir and Raei (2007) found a small correlation between Sukuks and Bonds that made their mixed portfolios had smaller Value-at-Risk than those of all conventional Bonds. Balcilar et al. (2016) and Hassan et al. (2018) stated that Sukuks had a dynamic correlation path against conventional Bonds and lower volatility than that of conventional bonds that benefit investment managers after placing Sukuk as their global equity portfolio strategies to diversify traditional risk and maintain target return. The second reason is that Hamzah et al. (2018) stated that since Sharia laws opposed the risk-shifting behavior of equity holders, Sukuk issuance supports risk-sharing to curb risk-shifting, unlike conventional bonds. The third reason, Grassa and Miniaoui (2018) discussed from the perspective of debt securities issuers. They said that in the Gulf Cooperation Countries from 2000 to 2015, firms prefer Sukuks to conventional Bonds when the issuers need large financing volumes and long-term maturities. These reasons made Sukuk a new class of securities that we believe always attract demands and supplies. With the principles of Islamic finance, some countries utilize Sukuk as a financial tool for societal wellbeing.

Green Sukuk is a typical financial tool that promises to use the proceeds for eligible green investments or projects, such as wind energy, electric vehicles and infrastructure, and solar parks. An investor can confirm the issuer's green-compliance from an external reviewer who provides an independent assessment of the sukuk's proceeding (Mardi et al., 2020). These reviewers can be the International Capital Markets Association (ICMA), the Climate Bond Initiative (CBI), or the ASEAN Capital Markets Forum (ACMF). The reviewers also set rules and standards to govern green securities, including Sukuk, such as ICMA's green bond principles, CBI green bond database requirements, or ACMF's green bond standards. External assessment ascertains investors that issuers meet market expectations and industry best practices.

However, the governance of green securities is not enough. Peng et al. (2018) suggested green financing in developing countries that it needs government support. Furthermore, large-scale green projects need long-term financing. Taghizadeh-Hesary and Yoshino (2020) said that green development lacks long-term financing, and most green technologies are relatively new and unreliable, risky, and commercially weaker than those of non-green technology. Therefore, Taghizadeh-Hesary and Yoshino (2020) said that green financing needs the development of public financing institutions, such as state investment banks.

Besides the needs for governmental supports, the Sukuk fundraiser inherently has an in-depth process of prioritizing ethical businesses and preventing any harmful effects project (Rahman et al., 2020). Moghul and Safar-Aly (2014) said that environmentalism's contemporary principles are

deeply embedded within classical Islamic law and ethics. Moreover, the governmental-indemnified facility would accomplish long-term financing and low yield investment problems. Therefore, the government must support the Islamic finance industry to promote a pro-environmental agenda through investment in green projects and other carbon-conscious initiatives. In the following discussion, this study discusses the sovereign green Sukuk, in which investors and reviewers need to estimate its environmental risks and prices.

To determine a generic Sukuk's price, some researchers claim some empirical price discrepancy between Sukuk and conventional bonds. Safari et al. (2013) and Naifar et al. (2017) found that Sukuk is different from conventional bonds in terms of comovement with global and regional uncertainty factors. These two assets are complementary and not substitutes. Ariff et al. (2018) said that sovereign Sukuk has a lower yield than that of a sovereign Bond. However, corporate Sukuk has a higher yield than that of corporate Bond. Putri et al. (2020) researched Indonesian government bonds and Sukuk from 2014 to 2017 and stated that SUN carries a higher risk level than SBSN. Cakir and Raei (2007) had empirical of Sukuk's liquidity and said that Sukuk generated a lower return and was less liquid than those conventional bonds. Furthermore, Ahroum et al. (2018), using 65 Malaysian Sukuk from February 2012 to October 2016, found that most Sukuk's buy-and-hold strategy slowed down market growth and secondary market volume.

1.2 Motivation

Although empirical results have found pricing discrepancies between Sukuk and conventional Bond, Sukuk's markets are efficient (Fama, 1970), such as investors emphasizing profit motive rather than putting green Sukuk as his priority placement (Siswantoro, 2018). Ayturk et al. (2017) said that Sukuks' issuance yield spread factors are similar to those of conventional Bonds, i.e. credit rating and maturity. Balcilar et al. (2016) said that shocks and volatilities of global stock markets positively exposed Sukuks, however, global Bond markets had negative spillover effects to Sukuks. Bhuiyan et al. (2019) found Malaysian Sukuk market did not reflect developed market bond indices. However, the market absorbed information from other emerging bond markets, such as Indonesia, Malaysia, India, and South Korea, except China. Unfortunately, Sukuks are generally illiquid securities (Hassan et al., 2018; Cakir and Raei, 2007) which had underdeveloped secondary market since their investors dominantly implement buy-and-hold strategy (Aasouli et al., 2018).

According to Zulhibri (2015), research on Sukuk should be pushed further into the mainstream of economics and finance. These sciences will identify the factors that influence Sukuk prices and differentiate between market risk approaches. After the findings, Sukuk's asset pricing needs the fundamental theory to explain the empirical valuation.

1.3 Research Gap

There is an alternative valuation methodology when Awaludin and Masih (2015) stated that the Sukuk yield curve also contains risk premium and liquidity. Moreover, Naifar et al. (2016) got some empirical findings that had implicitly confirmed the risk premium existence, i.e., corporate Sukuk price depended on stock price volatility. The government Sukuk was related to that of the global conventional stock market. Some researchers continued the research. Uddin et al. (2020) claimed

that Sukuk needs a different fundamental price model from that of conventional Bond, and they identified two risk factors for Sukuk that require risk premiums, i.e., Sukuk market risk and information asymmetry risk. The most classical conventional theory was that the interest rate contains an inflation rate (Fisher, 1896). Rahman et al. (2017) find that the inflation rate explained the movement of sovereign Sukuk yields using data from 2006 to 2013. Shahida et al. (2014) and Ng and Ariff (2019) found that credit rating change changed Sukuk price, and Sukuk price contained default risk premium. Another classical theory was that the government Bond yield curve contains sovereign and inflation risk premiums and liquidity premium (Durand, 1942). Inflation and default risk premiums are considered Sukuk market risk.

Both Sukuk and conventional bonds have similarity in market-risk based pricing. However, neither fundamental market risk nor asymmetric risk has explained green Sukuk pricing. Furthermore, Hachenberg and Schiereck (2018) found that green Bonds' yield was lower than that of non-green bonds. The lower the credit rating was, the larger is their pricing differences, e.g., the yield spread of a single A-rated Bond is as much as 3.88 bps. Since green and non-green attribution is about risk and market risk determines the price of both conventional bonds and Sukuk, a green-induced price gap must exist for Sukuk. Unfortunately, the description of these differences has not yet existed.

1.4 Research Contribution

This study determines market risks exposing Sukuk's investors. This research starts with waste production, which causes environmental risk. This research introduces environmental systemic risk and environmental reputation risk. The research utilizes these risks since they always exist in the future. Finally, this research manages to quantify the premium, which contributing layers within the Sukuk yield curve.

2 Model Development

2.1 Waste Generation

Remark 2.1. Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal (UNEP, 1989) defined a general-term of waste in article 2 clause one as *substances or objects disposed of or intended to be disposed off of or were required to be disposed of by the provisions of national law*. Most waste of industrial processes is harmful, which is called pollution. According to the Encyclopedia of Britannica, pollution is the release or removal of materials or substances into nature; the pollutant quantities are so large that nature can no longer recycle or neutralize them.

Definition 2.1. After getting a short-introduction of waste, we defined *a waste generation* as the flows of waste and pollution, which are by-products of humans' economic activities. The production of waste and pollution, directly and indirectly, aggravates the environment, social life, and governance (ESG).

Previous researches showed that there were so many sources of wastes. Bruvoll and Ibenholt (1997) found that the waste of Sweden manufacturing mainly came from material input. However, according to Bandara et al. (2007), waste generation is equivalent to population growth and average income. Benitez et al. (2008) determined four crucial factors of residential solid waste, i.e., education level, number of residents, and income. Brock and Taylor (2010) developed a *green Solow* model that income and population were pollution sources. Chhay (2018) found that the growth of municipal solid waste in China positively related to urban population growth, GDP, and energy consumption. Araiza-Aguilar (2020) made the municipal waste forecasting model in Mexico, and they found that the most important source of waste generation was population and followed by income and education level. Therefore, We develop a waste generation model covering all possible sources, i.e., the waste of final products and manufacturing processes' pollution.

In 1994, Copeland and Taylor thought that the pollution distribution was confined to a pollutant-generating community. In 2010, Brock and Taylor developed the Green Solow model, which implicitly represented world pollution. We assumed that pollution production could widely spread to other communities without borders. We consider the population and its economic activities as the source of waste, so waste production results from world population and production activities. Like those models of *green Solow* (Brock and Taylor, 2010), and final consumption expenditure of households (Mazzanti and Zoboli, 2008), we develop a composite unit of wastes and pollutions which they together are harmful to nature.

The components of waste and pollution are as follows:

1. the number of basic wastes that the garbages of basic needs, C_B ,

$$C_B = \theta_B P \quad \text{Equation 1}$$

where θ_B is the waste portion of the primary products and conversion of natural destruction unit, and P is the population,

2. the waste amount of non-basic goods or services, C_L ,

$$C_L = \theta_L Y \quad \text{Equation 2}$$

where θ_L is the waste portion of the non-basic products or services and conversion of natural destruction unit, and Y is the income,

3. The amount of production waste and pollution that the higher the production level is, the higher is the waste, Y_P ,

$$Y_P = \theta_P Y \quad \text{Equation 3}$$

where θ_P is the waste portion of manufacturing or servicing processes and conversion of natural destruction unit.

We develop waste production model (G) using constant elasticity of substitution (CES) function. There is no dominant waste-producer in the world, and all countries generate waste. The model is as follow:

$$G = \sum_{k=1}^K \left(\frac{x_{B,k}}{K} C_{B,k}^\rho + \frac{x_{L,k}}{K} C_{L,k}^\rho + \frac{x_{P,k}}{K} Y_{P,k}^\rho \right)^{1/\rho} \quad \text{Equation 4}$$

where ρ is a substitution rate, k is a subindex of a country, K is the number of countries in the world, $x_{B,k} \in [0,1]$ is the waste share parameter of basic consumptions, $x_{L,k} \in [0,1]$ is the waste share parameter of non-basic consumptions, and $x_{P,k} \in [0,1]$ is the waste share parameter of by-product waste.

∴ waste sources are non substitutable, $\rho \approx 0$,

and the sum of all waste sharing is always 100%, or $\sum_{k=1}^K \left(\frac{x_{B,k}}{K} + \frac{x_{L,k}}{K} + \frac{x_{P,k}}{K} \right) = 1$

∴ Equation 4 becomes: $\lim_{\rho \rightarrow 0} G = \lim_{\rho \rightarrow 0} \sum_{k=1}^K \left(\frac{x_{B,k}}{K} C_{B,k}^\rho + \frac{x_{L,k}}{K} C_{L,k}^\rho + \frac{x_{P,k}}{K} Y_{P,k}^\rho \right)^{1/\rho}$

$$G = \prod_{k=1}^K \left(C_{B,k}^{x_{B,k}} C_{L,k}^{x_{L,k}} Y_{P,k}^{x_{P,k}} \right)^{\frac{1}{K}} \quad \text{Equation 5}$$

Using Equation 5, we can split to measure the waste production of a certain country from the rest of the world. The waste contribution from a country, “1”, is as follow:

$$\therefore G = \left(C_{B,1}^{\frac{x_{B,1}}{K}} C_{L,1}^{\frac{x_{L,1}}{K}} Y_{P,1}^{\frac{x_{P,1}}{K}} \right) \cdot \prod_{k=2}^K \left(C_{B,k}^{\frac{x_{B,k}}{K}} C_{L,k}^{\frac{x_{L,k}}{K}} Y_{P,k}^{\frac{x_{P,k}}{K}} \right)$$

$$\therefore G_1 = \frac{G^K}{\prod_{k=2}^K \left(C_{B,k}^{x_{B,k}} C_{L,k}^{x_{L,k}} Y_{P,k}^{x_{P,k}} \right)} \quad \text{Equation 6}$$

We can simplify the model of world waste production as follow:

$$\therefore A_1^{\frac{B_1}{K}} A_2^{\frac{B_2}{K}} A_3^{\frac{B_3}{K}} \dots A_K^{\frac{B_K}{K}} = A_T^B$$

$$A_T = \left(\prod_{k=1}^K A_k \right)^{1/K}$$

$$KB \ln A_T = B_1 \ln A_1 + B_2 \ln A_2 + B_3 \ln A_3 + \dots + B_K \ln A_K$$

$$B = \frac{\sum_{k=1}^K B_k \ln A_k}{K \ln(A_T)}$$

$$\begin{aligned} \therefore C_B &= (\prod_{k=1}^K C_{B,k})^{1/K}, C_L = (\prod_{k=1}^K C_{L,k})^{1/K}, \text{ and } Y_P = (\prod_{k=1}^K Y_{P,k})^{1/K} \\ x_B &= \frac{\sum_{k=1}^K x_{B,k} \ln C_{B,k}}{K \ln(C_B)}, x_L = \frac{\sum_{k=1}^K x_{L,k} \ln C_{L,k}}{K \ln(C_L)}, \text{ and } x_P = \frac{\sum_{k=1}^K x_{P,k} \ln Y_{P,k}}{K \ln(Y_P)} \end{aligned}$$

Therefore, waste flows all over the world are as much as:

$$G = C_B^{x_B} C_L^{x_L} Y_P^{x_P} \quad \text{Equation 7}$$

where $x_B + x_L + x_P = 1$

2.2 Accumulative Waste

Definition 2.2. *Accumulative waste* (A) is the balance of waste and pollution in the world, potentially causing ESG problems. Waste generation (G), as an incoming flow, increases the potential problems amid nature always finds a way to heal itself. The remedies of a damaged environment, as an outgoing flow, consist of both natural reversion and green technology (R).

$$dA = G dt - dR \quad \text{Equation 8}$$

where $dR = \max(0, \mu_R A dt + \sigma_R A dz)$, $\mu_R \geq 0$, and $\sigma_R \geq 0$.

Remarks 2.2. Pollution and waste emissions data is always publicly available. The imbalanced flows between waste generation and remedy either enlarges or shrinks up the waste accumulation. The data makes people aware of the deteriorating state of the environment. People realize that the environmental risks will be unbearable for the whole world one day, instead of a single nation.

Lemma 2.1. The expansion of waste generation's mean and variance worries people.

Proof. We develop a waste acceleration model (dG) from Equation 7 to get its component specification. The partial stochastic differential equation of waste generation is as follow:

$$\begin{aligned} dG &= \frac{\partial G}{\partial C_B} dC_B + \frac{\partial G}{\partial C_L} dC_L + \frac{\partial G}{\partial Y_P} dY_P + \frac{1}{2} \frac{\partial^2 G}{\partial C_B^2} dC_B^2 + \frac{1}{2} \frac{\partial^2 G}{\partial C_L^2} dC_L^2 + \frac{1}{2} \frac{\partial^2 G}{\partial Y_P^2} dY_P^2 \\ &+ \frac{1}{2} \frac{\partial^2 G}{\partial C_B \partial C_L} dC_B dC_L + \frac{1}{2} \frac{\partial^2 G}{\partial C_B \partial Y_P} dC_B dY_P + \frac{1}{2} \frac{\partial^2 G}{\partial C_L \partial Y_P} dC_L dY_P \end{aligned} \quad \text{Equation 9}$$

$$\text{where: } \frac{\partial G}{\partial C_B} = x_B \frac{G}{C_B}, \text{ and } \frac{\partial^2 G}{\partial C_B^2} = x_B(x_B - 1) \frac{G}{C_B^2}$$

$$\frac{\partial G}{\partial C_L} = x_L \frac{G}{C_L}, \text{ and } \frac{\partial^2 G}{\partial C_L^2} = x_L(x_L - 1) \frac{G}{C_L^2}$$

$$\frac{\partial G}{\partial Y_P} = x_P \frac{G}{Y_P}, \text{ and } \frac{\partial^2 G}{\partial Y_P^2} = x_P(x_P - 1) \frac{G}{Y_P^2}$$

$$\frac{\partial^2 G}{\partial C_B \partial C_L} = x_B x_L \frac{G}{C_B C_L}, \text{ and } \frac{\partial^2 G}{\partial C_B \partial Y_P} = x_B x_P \frac{G}{C_B Y_P}$$

$$\frac{\partial^2 G}{\partial C_L \partial Y_P} = x_L x_P \frac{G}{C_L Y_P}$$

We get some stochastic differential equations of C_B , C_L , and Y_P using Eq. 1, 2, and 3, as follows:

$$dC_B = \theta_P(\mu_P P dt + \sigma_P P dz_P)$$

$$dC_B^2 = \theta_P^2 \sigma_P^2 P^2 dt$$

$$dC_L = \theta_L Y \left((\alpha (s_K^Y - \delta) dt + \sigma_K dz_K) + (1 - \alpha)(\mu_L dt + \sigma_L dz_L) + \frac{1}{2} \alpha(\alpha - 1)(\sigma_K^2 + \sigma_K^2 - \sigma_K \sigma_L \rho_{K,L}) dt \right)$$

$$dC_L^2 = \theta_L^2 Y^2 (\alpha^2 \sigma_K^2 + (1-\alpha)^2 \sigma_L^2 + 2\alpha(1-\alpha)\sigma_K\sigma_L\rho_{K,L}) dt$$

$$dY_P = \theta_P Y \left(\left(\alpha \left(s \frac{Y}{K} - \delta \right) dt + \sigma_K dz_K \right) + (1-\alpha)(\mu_L dt + \sigma_L dz_L) \right) + \frac{1}{2} \theta_P Y \alpha (\alpha - 1) (\sigma_K^2 + \sigma_L^2 - \sigma_K\sigma_L\rho_{K,L}) dt$$

$$dY_P^2 = \theta_P^2 Y^2 (\alpha^2 \sigma_K^2 + (1-\alpha)^2 \sigma_L^2 + 2\alpha(1-\alpha)\sigma_K\sigma_L\rho_{K,L}) dt$$

Because G depends on a production level, we analytically describe the Cobb-Douglas production or income function (Y) as follows:

$$Y = K^\alpha L^{1-\alpha} \quad \text{Equation 10}$$

where K is an investment or a capital stock variable, L is a labor variable, and α is a share parameter.

P , L , K , and R are following stochastic differential equations (SDEs) as follows:

$$dP = \mu_P P dt + \sigma_P P dz_P$$

$$dL = \mu_L L dt + \sigma_L L dz_L$$

$$dK = (sY - \delta K) dt + \sigma_K K dz_K$$

where s is a reinvestment rate and δ is a depreciation rate, dz is a brownian motion with normally distributed noise, i.e., $dz \sim N(\mu, \sigma^2)$ and μ is σ the drift and both are constant.

We can get the exponential drift of waste generation as follow:

$$\begin{aligned} E_t \left(\frac{1}{G} \frac{dG}{dt} \right) &= x_B \mu_P + (x_L + x_P) \alpha \left(s \frac{Y}{K} - \delta \right) + (1-\alpha) \mu_L + \frac{1}{2} \alpha (\alpha - 1) (\sigma_K^2 + \sigma_L^2 - \sigma_K\sigma_L\rho_{K,L}) \\ &+ \frac{1}{2} x_B (x_L + x_P) (\alpha \sigma_P \sigma_K \rho_{P,K} + (1-\alpha) \sigma_P \sigma_L \rho_{P,L} - \sigma_P^2) \\ &+ \frac{1}{2} (x_P (x_P - 1) - x_L x_B) (\alpha^2 \sigma_K^2 + (1-\alpha) \sigma_L^2 + 2\alpha(1-\alpha) \sigma_K \sigma_L \rho_{K,L}) \end{aligned} \quad \text{Equation 11}$$

The exponential variance of waste generation is as follow:

$$\begin{aligned} \sigma_t^2 \left(\frac{1}{G} \frac{dG}{dt} \right) &= x_B^2 \sigma_P^2 + \alpha^2 (x_L + x_P)^2 \sigma_K^2 + (1-\alpha)^2 \sigma_L^2 + 2\alpha x_B (x_L + x_P) \sigma_P \sigma_K \rho_{P,K} + 2(1-\alpha) x_B \sigma_P \sigma_L \rho_{P,L} \\ &+ 2\alpha(1-\alpha) (x_L + x_P) \sigma_K \sigma_L \rho_{K,L} \end{aligned} \quad \text{Equation 12}$$

We simplify waste generation model of Equations 11 and 12 into as follow:

$$E_t(G) = G_0 e^{(W - X - 1/2 V^2)t}$$

$$\sigma_t^2 = \sigma_0^2 e^{V^2 t} \quad \text{Equation 13}$$

where W is positive components of $E_t \left(\frac{1}{G} \frac{dG}{dt} \right)$ in Equation 11,
:

$$\text{and } W = x_B \mu_P + (x_L + x_P) \alpha \left(s \frac{Y}{K} - \delta \right) + (1-\alpha) \mu_L + \frac{1}{2} x_B (x_L + x_P) \alpha \sigma_P \sigma_K \rho_{P,K}$$

X is negative components of $E_t \left(\frac{1}{G} \frac{dG}{dt} \right)$ in Equation 11,

$$\text{and } X = \frac{1}{2} \alpha (1-\alpha) (\sigma_K^2 + \sigma_L^2 - \sigma_K \sigma_L \rho_{K,L}) + \frac{1}{2} x_B (x_L + x_P) \sigma_P^2$$

$$+ \frac{1}{2} (x_P (x_P - 1) - x_L x_B) (\alpha^2 \sigma_K^2 + (1-\alpha) \sigma_L^2 + 2\alpha(1-\alpha) \sigma_K \sigma_L \rho_{K,L})$$

$V^2 = \sigma_t^2 \left(\frac{1}{G} \frac{dG}{dt} \right)$, in Equation 12 and it is always positive.

Using Equation 8 and assuming $A > 0$, we derive the expected and the variance of accumulative waste as follow:

$$dA = G_0 e^{(W-X-1/2V^2)t} \left(1 + \int V dz + \frac{1}{2} \int V^2 dt + 0 \right) dt - \mu_R A dt - \sigma_R A dz$$

$$E_t \left(\frac{dA}{dt} \right) = G_0 e^{(W-X-1/2V^2)t} (1 + 0) - \mu_R A$$

$$E_t \left(\frac{A}{G_0} \right) = \frac{1}{W-X-1/2V^2+\mu_R} e^{(W-X-1/2V^2)t} \quad \text{Equation 14}$$

$$\sigma_t^2 \left(\frac{1}{A} \frac{dA}{dt} \right) = \sigma_R^2$$

$$\sigma_t^2(A) = e^{\sigma_R^2 t} \quad \text{Equation 15}$$

Assuming constant W, X, V , we get the expectation of the waste generation of Equation 13 and the waste accumulation of Equation 14 is as follow:

If the drift of waste generation is positive, $W > X + 1/2 V^2$, then $E_t(G(t+n+1)) > E_t(G(t+n))$. Since μ_R is always positive, and if the drift of waste generation is positive, then $E_t(A(t+n+1)) > E_t(A(t+n))$, see worsening scenario in Figure 2.1.

If the drift of waste generation is negative, $W < X + 1/2 V^2$, then $E_t(G(t+n+1)) < E_t(G(t+n))$. Since μ_R is always positive and the drift of waste generation is negative, then $\mu_R > X + 1/2 V^2 - W$, to keep $A_t > 0$ and $E_t(A(t+n+1)) < E_t(A(t+n))$, see improving scenario in Figure 2.1.

Assuming constant V , we infer from Equation 13 that the variance of waste generation is always exponentially growing.

The variance of waste accumulation is as follow:

∴ Equation 8 and 15 show that σ_R is independent, and V does not change the variance of A .

∴ The variance of A is unexplainable with existing variables.

When the expectation of waste generation and accumulation are growing, and the variance of waste generation is always are growing, even though the variance of waste accumulation (σ_A) can be of any value, People know that their environments are deteriorating. ■

2.3 Environmental Systemic Risk

Remarks 2.3. When society uncontrollably devastates her environment, the deteriorating environment worries people (Lemma 2.1), and the financial market starts to perceive increasing wastes. Leboullenger (2017) said that there were two channels of climate or environmental risk, i.e., the first channel, chronic accumulative wastes that immediately destroy the environment, social, and governance life. The second channel is the incapability of dominant corporates to implement environmentally friendly production methods. Additionally, Hansen (2007) said that scientists had

a constraint to disperse the information of greenhouse gas-induced sea level rise, which was called "scientific reticence."

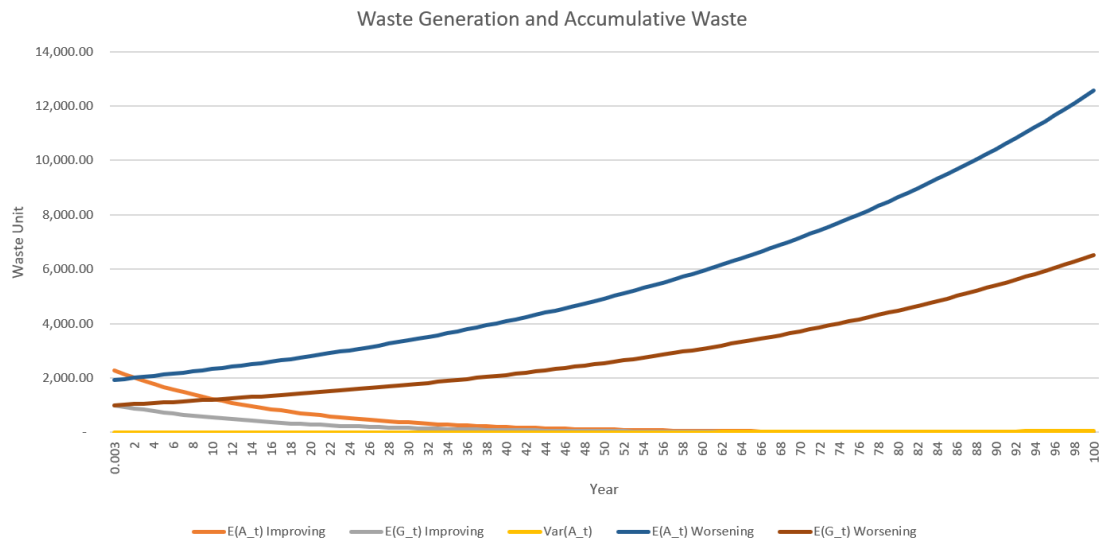


Figure 2.1. The simulation of waste growth and accumulation using Equation 13, 14, and 15 from overnight to a hundred years with improving and worsening scenarios. The parameters are $G_0=1000$, $X=0.3$, $V=0.25$, $\mu_R=0.5$, $\sigma_R=0.2$. When the situation worsening, $w > x + \frac{1}{2}v^2$, $W=0.35$ and $w - x - \frac{1}{2}v^2 = 0.02$. Otherwise, when the situation improving, $w < x + \frac{1}{2}v^2$, $W=0.27$, and $w - x - \frac{1}{2}v^2 = -0.06$.

The financial market and banking system have recognized *systemic risk*, which refers to the potential losses of the entire banking system or financial market because of the high correlation or clustering of banking or financial institutions. *Systemic risk* is a future large-scale or multidimensional crisis.

In 1992, Meadows et al. said people consume natural resources and produce pollutants at exceeding sustainable rates. Therefore, the young generation would face a declining quantity of food, energy, and production. Furthermore, Daly (2013) said that economic growth has certain costs, such as climate change from greenhouse gases and social and environmental costs.

Like the market and the system, environmental systemic risk attributes to comovements between environmental problems and other subsequent problems. The arctic ice loss changes the atmospheric circulation at high northern latitudes, causing cold winter extremes in the northern hemisphere (Tang et al., 2013), including the Siberian continent (Ogawa et al., 2018). The second effect of the loss is a late response of polar stratospheric cooling, which changes ozone concentration and ultraviolet radiation reaching the ground surface (Screen, 2013). The third is varying Arctic climate responses to increasing greenhouse gases (Screen, 2013). The last is sea-level rise, which will rise between 20 cm and 90 cm from 1996 to 2100 (Yohe and Schlesinger, 1998). Environmental systemic risk is also a future large-scale or multidimensional crisis.

Leboulenger (2017) said that climate or environmental systemic risk was future problems looming over the environment, extended to social, and then to the financial market. Does neither the sky nor the ocean has a physical border so that the pollution flows and spread out to other parts of the world, and it triggers environmental systemic. When the world is accumulating waste, the financial markets can gradually monetize and quantify the ESG damages.

Definition 2.3. *Environmental systemic risk* (π_E) is the event probability of natural calamity and its subsequent environmental disaster when the earth can no longer tolerate any additional waste. The current level of accumulative waste, A_t , triggers the systemic risk when $A_t \geq A_S$. However, the systemic event may gradually occur in the world, and scientists may not have any agreement of A_S level but can only estimate it, which $A_S \sim N(\mu_S, \sigma_S^2)$, where μ_S and σ_S are constant.

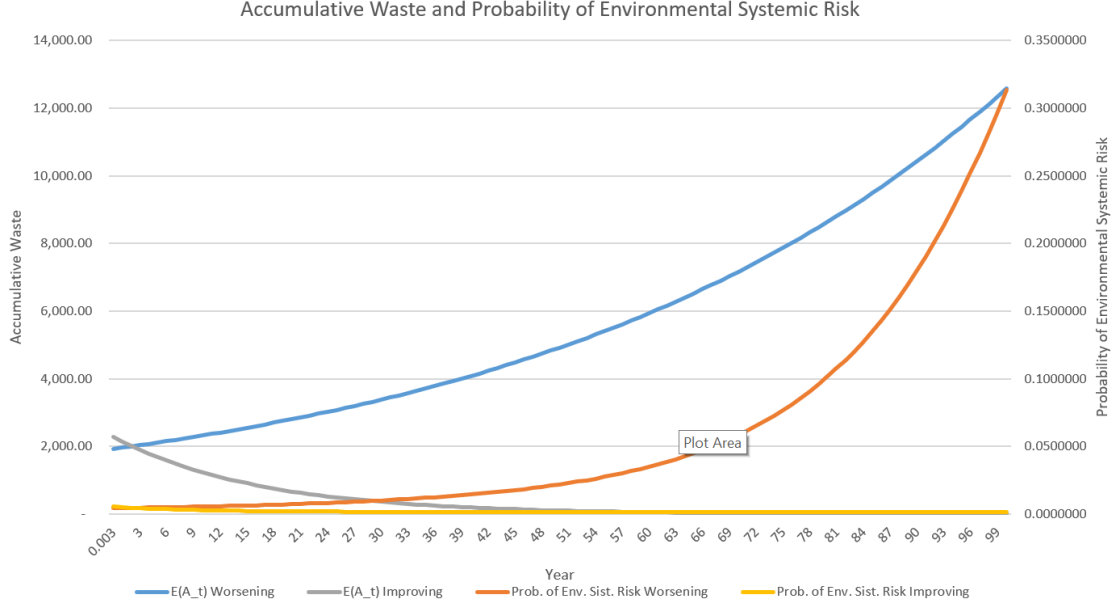


Figure 2.2. The simulation of environmental systemic risk probability using Equation 17 from overnight to a hundred years with improving and worsening scenarios. The parameters are those of Figure 2.1 and the accumulative waste of systemic event $A_S \sim N(15,000, 1,000^2)$.

Figure 2.2 shows that the level of accumulative waste can determine the probability of a systemic environmental event.

Using Equation 14 as velocity with acceleration, assuming constant W , X , and V , and using Value-at-Risk methodology, we can determine the time to 1% ($z=2.576$), 5% ($z=1.960$), or 10% ($z=1.645$) probability of systemic event as follow:

$$\int_{k=0}^{\tau} \frac{G_0}{W-X-1/2V^2+\mu_R} e^{(W-X-1/2V^2)k} dk = VaR$$

where $VaR = \mu_S - z\sigma_S$ since two-tail distribution and $VaR < \mu_S$.

$$\frac{G_0}{(W-X-1/2V^2+\mu_R)(W-X-1/2V^2)} (e^{(W-X-1/2V^2)\tau} - 1) = VaR$$

$$\frac{G_0}{(W-X-1/2V^2+\mu_R)(W-X-1/2V^2)} e^{(W-X-1/2V^2)\tau} = VaR + \frac{G_0}{(W-X-1/2V^2+\mu_R)(W-X-1/2V^2)}$$

$$e^{(W-X-1/2V^2)\tau} = VaR \frac{(W-X-1/2V^2+\mu_R)(W-X-1/2V^2)}{G_0} + 1$$

$$\therefore \left| \frac{VaR}{G_0} (W-X-1/2V^2+\mu_R)(W-X-1/2V^2) \right| \ll 1$$

$$\therefore (W-X-1/2V^2)\tau = \frac{VaR}{G_0} (W-X-1/2V^2+\mu_R)(W-X-1/2V^2)$$

$$\tau = \frac{VaR}{G_0} (W-X-1/2V^2+\mu_R) \quad \text{Equation 16}$$

Proposition 2.2. The probability of environmental systemic event is p , and when the event happens, Sukuk payoff is at recovery level, R . Otherwise, Sukuk makes full payment payoff. The risk causes Sukuk to contain an additional layer of environmental systemic risk premium in the term structure of Sukuk yield.

Proof. We use the lattice model to figure out the environmental systemic risk. In this model, every day, the risk exposes the world; either environmental disaster occurs or does not.

From Figure 2.2, the probability of environmental system risk at time “ t_1 ” is as follow:

$$p(t_1) = CDF(A_{t_1}, \mu_S, \sigma_S) \quad \text{Equation 17}$$

where Equation 14 can determine A_{t_1} .

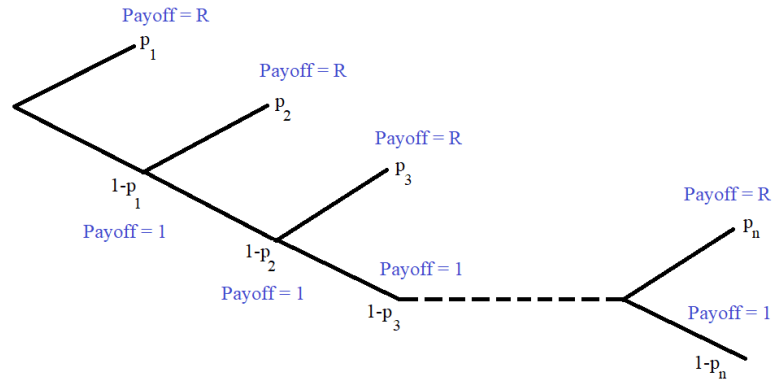


Figure 2.3. The probability trees of the environmental systemic event. Each branch represents a period. The probability of event at “ n ”-th branch is $p(A_{t_{n-1}, t_n})$ with R payoff. After the event, the branch is discontinued. Other branches with no event are continued to the following years.

Determining the spot environmental-systemic-risk premium of each maturity, π_{E, t_{n-1}, t_n} , we equalize the present values of environmental systemic risky contract and non-risky contract with assuming flat yield curve and the probability tree as that of Figure 2.3 as follows:

$$e^{-(\pi_o + \pi_{E,0,k})k} = \mathbf{1} \cdot \prod_{t=1}^k (1 - p_t) e^{-\pi_o k} + R p_k \prod_{t=1}^{k-1} (1 - p_t) e^{-\pi_o k}$$

$$\text{Using annuity solution: } \frac{\mathbf{1}}{(1 + \pi_o + \pi_{E,0,k})^k} = \frac{\mathbf{1} \prod_{t=1}^k (1 - p_t)}{(1 + \pi_o)^k} + \frac{R p_k \prod_{t=1}^{k-1} (1 - p_t)}{(1 + \pi_o)^k}$$

$$\frac{\mathbf{1}}{(1 + \pi_o + \pi_{E,0,k})^k} = \frac{\prod_{t=1}^{k-1} (1 - p_t)}{(1 + \pi_o)^k} (\mathbf{1} - p_k + R p_k)$$

$$\pi_{E,0,k} = \frac{\mathbf{1} + \pi_o}{\sqrt[k]{(1 - p_k + R p_k) \prod_{t=1}^{k-1} (1 - p_t)}} - \mathbf{1} - \pi_o \quad \text{Equation 18}$$

where π_o is other risk premiums. ■

2.4 Environmental Reputation Risk

Remarks 2.4. Most developed countries have their environmental agency. The agency is the source of information to adopt, implement, evaluate some policies, and enforce the law in some countries. In the United States, the Environmental Protection Agency (EPA) is an independent governmental

body established in July 1970. It has the power to issue regulations, such as the Clean Air Act, the Clean Water Act, and the Oil Pollution Act. It also has the authority to fine, to give sanctions, to decide other measures. In European countries, the European Environmental Agency (EEA) was established by the European Economic Community. Its management board comprises representatives from its 33 member states in the European Economic Community. Its environmental policy must relate to its member's domestic policies and other international policies. EEA does not have any enforcing law, but it has revealed some environmental problems in the countries, such as implementing Common Agricultural Policy, Common Fisheries Policy, and Water Framework Directive.

Definition 2.4. *Reputational risk* is a potential problem of an entity (a company, a country, and a region) that will be unveiled in the future. The problem will cause profoundly negative perceptions from its customers, shareholders, bondholders, or investors, regulators, and local government (BIS, 2019).

Like reputation risk, we define an *environmental reputation risk* is a potential problem when an entity decides not to be green, such as: corporate not to operate with ESG requirement, and Bond or Sukuk issuer not to sell the green version.

However, some managers and some governments have environmental inattentiveness, vague government regulations, and obscure natural disaster. The managers and the countries may or may not adopt the ESG direction or rule by relying on other complying managers.

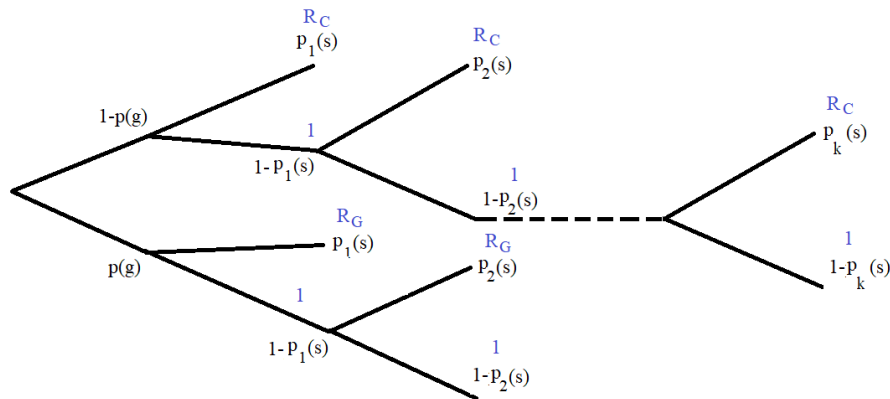


Figure 2.4. The trees of reputational event. $p(g)$ is the probability to choose a green financing, and $p(s)$ is the probability of environmental systemic event. Each branch represents a period. The probability of event at “ n ”-th branch is $p(A_{t_{n-1}, t_n})$. After the systemic event, the branch is discontinued and its payoff is either R_G for a green project (R_G is R in Proposition 2.2) or R_C for a non-green or conventional project, where $1 > R_G > R_C$.

Proposition 2.3. The green financing project must have lower environmental reputation risk, π_{R_G} , than that of conventional, π_{R_C} . Therefore, the green project must suffer less than that of conventional.

Proof. We adopt a lattice model to establish the risk premium model. In this world, a government has two choices, either to issue a green or a conventional financing, which has p_g and $p_{\bar{g}}$ probabilities. There is always a systemic risk in discrete time, which contains a reputation risk, a

much as p_{t+n} at time $t+n$. The general model of green financing contract and that of conventional with “k”-year maturity using the probability trees in Figure 4 is as follow:

$$e^{-(\pi_o+\pi_{E,0,k}+\pi_{R,0,k})k} = 1 \cdot \prod_{t=1}^k (1-p_t) e^{-\pi_o k} + (p_g R_g + (1-p_g) R_c) p_k \prod_{t=1}^{k-1} (1-p_t) e^{-\pi_o k}$$

$$\text{Using annuity solution: } \frac{1}{(1+\pi_{o,0,k}+\pi_{E,0,k}+\pi_{R,0,k})^k} = \frac{(R_g p_g + R_c (1-p_g)) p_k \prod_{t=1}^{k-1} (1-p_t)}{(1+\pi_{o,0,k})^k} + \frac{1 \prod_{t=1}^k (1-p_t)}{(1+\pi_{o,0,k})^k}$$

$$\frac{1}{(1+\pi_{o,0,k}+\pi_{E,0,k}+\pi_{R,0,k})^k} = \frac{(R_g p_g p_k + R_c (1-p_g) p_k + (1-p_k)) \prod_{t=1}^{k-1} (1-p_t)}{(1+\pi_{o,0,k})^k}$$

$$\pi_{R,0,k} = \frac{1+\pi_{o,k}}{\sqrt[k]{(R_g p_g p_k + R_c (1-p_g) p_k + (1-p_k)) \prod_{t=1}^{k-1} (1-p_t)}} - 1 - \pi_{o,k} - \pi_{E,0,k} \quad \text{Equation 19}$$

where R_G with p_g probability, R_C with $p_{\bar{g}}$, which is the recovery rate of green contract and plain-vanilla or conventional contract, and $\pi_{R,0,k}$ is the environmental reputation risk premium of conventional contract.

Since Sukuk holder would suffer additional environmental reputation risk at the systemic event, Sukuk should give compensation or positive premium, as much as $\pi_{R,0,k}$ which Equation 18 can prove that :

$$\therefore \pi_{R,0,k} \begin{cases} \text{if } p_g = 1, \text{ then } \frac{1+\pi_{o,k}}{\sqrt[k]{(R_g p_g p_k + (1-p_k)) \prod_{t=1}^{k-1} (1-p_t)}} - 1 - \pi_{o,k} - \pi_{E,0,k} \\ \text{if } p_g = 0, \text{ then } \frac{1+\pi_{o,k}}{\sqrt[k]{(R_c (1-p_g) p_k + (1-p_k)) \prod_{t=1}^{k-1} (1-p_t)}} - 1 - \pi_{o,k} - \pi_{E,0,k} \end{cases}$$

$R_G|_{p_g=1} > R_C|_{p_g=0}$ and assuming constant p_g and p_t

$$\therefore \pi_{R,0,k}|_{p_g=1} < \pi_{R,0,k}|_{p_g=0}$$

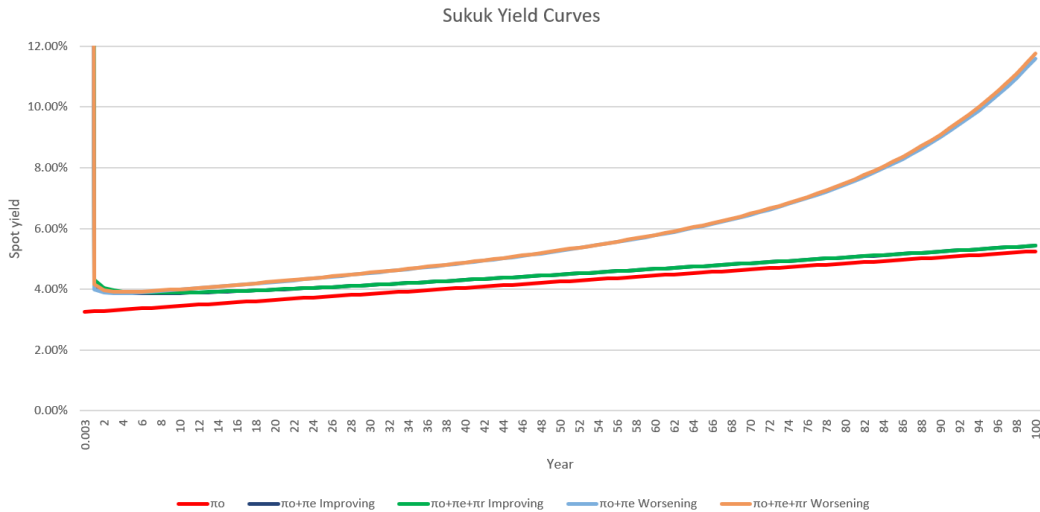


Figure 2.5. The simulation of environmental systemic risk probability using Equation 18 and 19 from overnight to a hundred years with improving and worsening scenarios. The parameters are those of Figure 2.2, $R_G = 40\%$, $R_C = 0\%$, and $p_g = 5\%$.

As shown in Figure 2.5, the results of Equations 18 and 19 are spikes from overnight to a year maturity that indicate correction needs. The environmental risk premiums are consistently increasing

for the worsening situation and decreasing for improving the situation. However, the simulation's reputation risk premium is only 1.3 bp for 30-year worsening, which is much smaller than that of Hachenberg and Schiereck (2018). A small reputational risk premium might discourage green financing and other pro-environmental agendas.

3 Conclusion

In this model development, as Zulhibri (2015) suggests, to analyze using mainstream finance, we have enriched Sukuk yield curves such as those of Durand (1942) and Awaludin and Masih (2015). We made a hypothetical unit to measure waste injury to nature and have added up two layers in the term structure of Sukuk yield, i.e., environmental systemic risk premium and environmental reputation risk premium.

The level of pollution and waste can be so high to trigger the systemic risk. The risk exposes all financing securities in the world. Since the systemic event is in waiting, we can determine the spot term structure of the risk premiums to the securities.

The emergence of green financing contracts creates an opportunity for adverse selection, either to enter a green financing contract or a non-green contract. In the systemic risk event, the non-green contract exposes the holder to the reputation risk, which can be enormous.

Like plain-vanilla Bond, the research suggests adjusting the current term structure of Sukuk yield with environmental risk premiums, and the term structure determines Sukuk pricing

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