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Hoard or Exploit? Intergenerational Allocation of Exhaustible Natural Resources

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Abstract: In this paper, a "general equilibrium" (GE) model was developed for the allocation of exhaustible natural resources to examine the impact of different extraction scenarios on intergenerational economic welfare. A stylized GE model was applied to Israel's natural gas (NG) market to evaluate economic indicators resulting from NG-extraction scenarios: a baseline scenario based on current policy in the NG sector, a conservative scenario based on a lower extraction rate, and an intensive scenario based on a faster extraction rate. The impact of various resource income-allocation strategies on intergenerational economic welfare was examined through the mechanism of a "sovereign wealth fund" (SWF). The results indicate that a higher NG-extraction rate combined with an appropriate investment strategy for NG profits is preferable from an economic perspective compared to a conservative rate. Investment of the government take from the NG market in research and development (R&D) of renewable electricity production can sustainably increase economic welfare.

Keywords: economic welfare; energy; exhaustible resource; general equilibrium model; sovereign wealth fund (SWF); natural gas

1. Introduction

Since the discovery of 900 billion cubic meters (BCM) of natural gas (NG) offshore in Israel, the country has been working to develop its natural resources and to establish a policy for its sector. Like many other countries, Israel is encouraging the transition to NG as a primary energy source, with its many advantages for the consumer, the economy, and the environment [1–3]. The NG reserves exceed the forecasted domestic consumption for the next 40 years [4]. The decision concerning the proportion of the gas reserves that should be preserved for domestic needs, and how much to export, is particularly complex. On the one hand, gas exports are expected to enrich the government's take and serve as a catalyst for improving Israel's relations with its neighbors. On the other hand, maintaining a large reserve of the gas for domestic use may serve as a stimulus for the transition [5].

In the current research, a novel approach was developed to analyze decisions regarding the extraction path of non-renewable resources, and particularly NG. The research considers the impact of the immediate use of these resources versus a lower level of exploitation over time in the Israeli market. The case of Israel, a country with a small open economy that was recently endowed with a NG windfall, can serve as an example for other countries, especially those with small open economies that have recently discovered exhaustible natural resources.

In this paper, an economic framework was established to address the main questions concerning the preferred extraction of exhaustible resource management strategy by determining a mechanism for allocating the resource between current and future generations and investigating the impact of resource-revenue allocation on economic welfare using GE methodology. Specifically, an intergenerational policy of allocating exhaustible natural resources was determined and the impact of different extraction scenarios on the economic welfare of society was calculated. The model was then applied to the Israeli NG market to evaluate economic indicators emerging from different NG-extraction scenarios. The current research in the NG field is conducted using theoretical models of economic growth, and it examines the impact of resource income-allocation strategies. To the best of our knowledge, this has never been done for the Israeli NG sector.

The current research can be used to draw up policies and to identify the effects on macroeconomic indicators. Moreover, it can serve as a tool to verify whether policies and regulations regarding exhaustible resources are valid, suitable, and adequate for the goals and objectives of this policy and regulation. The proposed model can be adapted by different countries and different sectors while adjusting case-specific characteristics.

The paper continues as follows. In Section 2, we provide a literature review. Section 3 describes the methodological approach and model specifications. Section 4 provides the background for the Israeli NG sector. Section 5 describes the NG extraction scenarios including the data sources. Section 6 provides the simulation results for the different NG extraction scenarios in the Israeli market. Section 7 provides a discussion of the results and policy recommendations. The last section provides some conclusions.

2. Literature Review

Exhaustible natural resources (NR) are defined as natural materials that have an extremely slow growth rate relative to their rate of consumption, putting them at risk for complete depletion. Oil, coal, natural gas (NG), and metals are some examples of NR [6]. Dasgupta and Heal [7] characterize an exhaustible resource as nonrecyclable, with a nil growth rate. Furthermore, it serves as an essential input for production. Accordingly, decisions made today about exhaustible resource extraction have consequences for the welfare of both current and future generations [8–10].

Concern about limited and exhaustible resources is an age-old issue and was raised by Thomas Malthus in his classic book published in 1798. Maltus suggested that rapid population growth would exceed the carrying capacity of the land's limited natural resources [11]. This theory was later expanded to include the availability of other exhaustible resources such as fossil fuels and mineral deposits. Nevertheless, Malthus's pessimistic prediction did not come to pass because, as economists suggest, resource scarcity can be forestalled by technological progress, changes in consumer preferences, and appropriate price signaling (see, for example, [12–14]).

Many questions have been raised regarding exhaustible natural resources. The basic questions addressed by researchers were: How should resource extraction be optimally allocated over time [12]? Can a market economy with exhaustible resources reach an optimal equilibrium [15]? What are the conditions needed to avoid a drop in the level of per capita consumption in the long run [8]? What are the necessary conditions for making the use of exhaustible resources compatible with sustainable development [14]? How are resources extracted over time in a market economy [16]? Is the market efficient at allocating the exhaustible resource [7]? What are the implications of resource exhaustibility in the context of economic growth [17]? What is the optimal pricing and taxation policy [18]?

The management of an exhaustible resource has a temporal dimension and long-lasting effects. Decisions taken now regarding the management of such resources depend on price dynamics, speed of technological progress, and changes in tastes and preferences [19].

The problem of intergenerational equality looms large in natural resource and environmental planning, while sustainable development is essential for economic welfare and growth [19]. Benchekroun and Withagen [20] showed that it is not necessarily the present generation that benefits most from a windfall of resources. The question of whether it is possible to maintain a non-declining

per capita income has a long-lasting effect, emphasizing the importance of relying on objective methodology in the decision-making process. One of the basic arguments encompassing exhaustible resources concerns whether governments can influence intergenerational income distribution, justify governmental involvement, and know-how to measure its outcomes [16]. In practice, the relationship between economic growth and the use of exhaustible natural resources must be a basic principle in formulating policies and making decisions with long-term impacts. This is especially important in the case of public resources that are not distributed effectively by market forces [21,22].

The discovery of exhaustible natural resources, especially those used to produce energy, can be a blessing for a country by easing the challenges of energy security and supply reliability. However, history shows that this blessing in some cases may become a curse when resource windfalls lower growth by crowding out the production of the internationally traded sector [23]. Therefore, there is a need for comprehensive analyses of the necessary policy governing these resources that will ensure long-term sustainable economic growth. Such a policy must delineate the rate of resource extraction and allocation across generations, the taxation scheme, and government revenues for utilizing the resource's value. Policy setting is essential for countries in which exhaustible resources have been recently discovered.

Many previous studies have demonstrated the impact of developing management strategies for exhaustible natural resource wealth including NG. However, researchers did not agree upon the favorable strategy of exhaustible resource management. Some recent studies suggest that resources should not be depleted within a short time horizon [24–26], while others suggest that countries can overcome economic degradation resulting from resource depletion [27–30]. Experience in countries such as Norway, which have succeeded in utilizing oil revenues to promote economic growth, proves that it is mainly the management of the natural resource revenues that leads either to economic growth or to resource curse [29]. Therefore, exhaustible natural resource management is essentially a matter of policy, and proper management can lead to economic growth. Setting a management strategy that relies on objective and comprehensive analyses in considering the economic impacts of exhaustible resources is essential for the efficient management of a nation's wealth.

At present, 900 billion cubic meters (BCM) of NG were discovered offshore Israel. Historically dependent on coal and oil imports, Israel has become self-sufficient in its primary energy supply for power generation since 2013. As in many other countries, Israel has encouraged the transition from coal and oil to NG as a primary energy source not only for electricity, but also industrial production. However, heated public debate has arisen around the question of whether to maintain a slow extraction rate to preserve the reserves for domestic use or to accelerate the extraction by allowing a high rate of export.

Since the discovery of Israel's NG fields, many studies have been written on a variety of issues related to its management [4]. These recent studies are summarized in Table 1.

Table 1. Recent studies covering the Israeli natural gas (NG) sector.

Reference	Aims	Methods	Key Findings
[31]	How big of a role should NG play in Israel's energy balance?	Analyzing data from 2009	A combination of demand management and utilization of several energy sources, particularly adding non-fossil fuel alternatives, enhances robustness; A strategy that rapidly enhances the use of NG in Israel can both be consistent with the interests of the Israeli population and provide security against various risks.
[32]	Analysis of potential effects of the Israeli windfall on its energy security and relations with its neighbors	Qualitative research	An overview of the Israeli NG sector

Table 1. *Cont.*

Reference	Aims	Methods	Key Findings
[2,33]	The process of establishing a management strategy for NG resources in Israel	Qualitative research	Israel's policy decisions on its NG sector are highly influenced by two factors: lack of government involvement in establishing an infrastructure and the assurance of a competitive gas market.
[34]	Opportunities and challenges offered by East Mediterranean gas to countries (including Israel) and investors in the region	Qualitative research	East Mediterranean gas is more likely to be a game changer for local energy markets than for regional or international ones. LNG is the favored export option for Israel's NG.
[35]	Israel NG export options	Literature review and analysis	Israel's potential as a NG exporter, although important nationally, is small in global terms.
[36]	Insights into the energy security aspects related to NG discoveries in Israel	Analysis of various policy documents and seeking the use of the expression "energy security"	Numerous discursive means have been used to portray energy as an urgent existential issue for Israel, and to justify the framing of energy as a matter of national security.
[3]	Effects of the newly introduced NG resources on the Israeli economy	CGE	Initiating export of NG from the discovered reserves may have an overall beneficial impact across most key indicators.
[37]	To investigate the effect of reduced NG import from Egypt with the evolution of domestic gas production on the Israeli economy	Extended computable general equilibrium CGE model	Poor households will be more positively affected by domestic gas production than rich ones due to their composition of factor income and their higher expenditure shares for energy-intensive commodities.
[38]	To review the Israeli NG sector, focusing on economic and geopolitical aspects	Quantitative research	Recommendations were given on increasing the consumption of NG in the domestic market; expanding the gas-transmission system; encouraging the construction of distribution networks; providing infant industry protections to additional reservoirs and setting up a joint infrastructure to enable their connection and remove export barriers.
[39]	Identifying critical factors affecting energy policy formulation in Israel following the NG discoveries	Questionnaire/interviews with energy experts in Mediterranean countries.	Techno-economic and geopolitical factors are the most important factors in setting energy policy in the Israeli sector; in considering gas-export options, decisions should be based not only on economic and/or financial factors, but on political factors as well.
[5]	Aspects, conflicts, benefits, and challenges that may accrue in the Israeli economy as a result of the extraction, use, and export of NG	Analysis of various policy documents from the different parliamentary and extra-parliamentary committees	Provides a theoretical analysis of the Israeli NG sector based on geographical, as well as regional and economic concerns.
[40]	To examine whether strengthening of the Israeli currency in recent years is a symptom of "Dutch disease"	Event study approach; data from 2009–2017	The classic symptom of Dutch disease is already in place in Israel, and gas-related news are found to have statistically significant impact and appreciate Israeli currency.
[41]	To examine the implications of Israel's NG discoveries in the Eastern Mediterranean.	Qualitative research	The book presents a picture of history, politics, and conflicts that shape the economics of energy and NG in Israel. Including the challenges of energy economy in Israel; Israel's relation with its neighbors in the Middle East; Dutch disease.

Most of the research on the Israeli NG sector has focused on export options, energy security, and the economic implications of the NG discoveries. However, Shaffer suggested conducting studies in the NG sector to identify new models of relationships between markets and regulation in this sector [33]. The author also underlined the importance of considering specific individual circumstances in Israel, while shaping the NG policy.

The current research aims to evaluate the influence of different NG-export scenarios on the Israeli economy as well as the social welfare of the different extraction options (for both domestic use and export) and government take management alternatives to identify the best path for current and future generations of Israelis. The national, regional, and sectoral macroeconomic effects of different NG-extraction scenarios in Israel are quantified including the effects on consumer utility, NG-extraction firms, state income, and electricity producers' profits. Furthermore, the impact of different resource income-allocation strategies on economic welfare is examined through the mechanism of a sovereign wealth fund (SWF).

The model presented in the current research is unique as it provides comprehensive market analyses referring to the different players in the relevant sectors and their different interests.

3. Model Specification

In this section, a simple macroeconomic growth model is proposed to evaluate different management scenarios and their welfare effects. A general model of resource extraction and use was set out, and the key economic players are explicitly represented in the model. The individual, resource-extraction firm, and producer problems were set up and necessary conditions for equilibrium were derived. Starting with the classic intertemporal choice model [42], we added an explicit definition of the consumer problem from Agnani et al. [10]. Building on Andersen [43], the government take was modeled based on Israeli regulations using SWF as a mechanism for transferring income to the public. The electricity producers' problem is defined based on Klump, and Willman [44]. These models were adjusted in order to comply with the regulations in the Israeli NG sector.

The economy in the current model consists of the exhaustible resource-extraction sector, the electricity-generation sector, the government, and two generations of consumers. In the following section, the different sectors of the economy are described. The study does not seek to identify the optimal path of NG extraction, but rather to compare three scenarios of NG extraction considered by stakeholders, as described in Section 5.

Consider a two-sector economy (the exhaustible resource-extraction sector and the electricity sector) with NG and renewable energy resources as the only inputs used for power generation. The justification for this approach is in line with Vousden [45], who emphasized that the essential features regarding exhaustible natural resources are more conveniently isolated when they are the only inputs into the model. This assumption reflects the Israeli electricity sector in which the main expenses are for fuel, comprising almost 40% [46]. We also assumed that NG is used only for power generation, as in the Israeli energy economy 80% of NG is used for electricity. Furthermore, the NG reserves discovered in Israel are very significant relative to the size of the Israeli economy and are expected to generate a comparative advantage. These fields provide an opportunity for Israel, considered an "energy island" (in light of Israel's disconnected energy infrastructure system with neighboring states), to reduce its energy dependency [7,33,36,37]) and are expected to provide a solution to the electrification of the country's energy market.

Figure 1 graphically depicts the sectors in the economy covered by the model and the relationships between them. The dashed lines in Figure 1 depict the exported amounts of NG that are not counted in calculating the consumer utility since only the welfare of domestic citizens was examined. However, the taxes paid on these amounts are included in the model, since they are collected by the government and transferred to Israeli consumers and to the SWF.
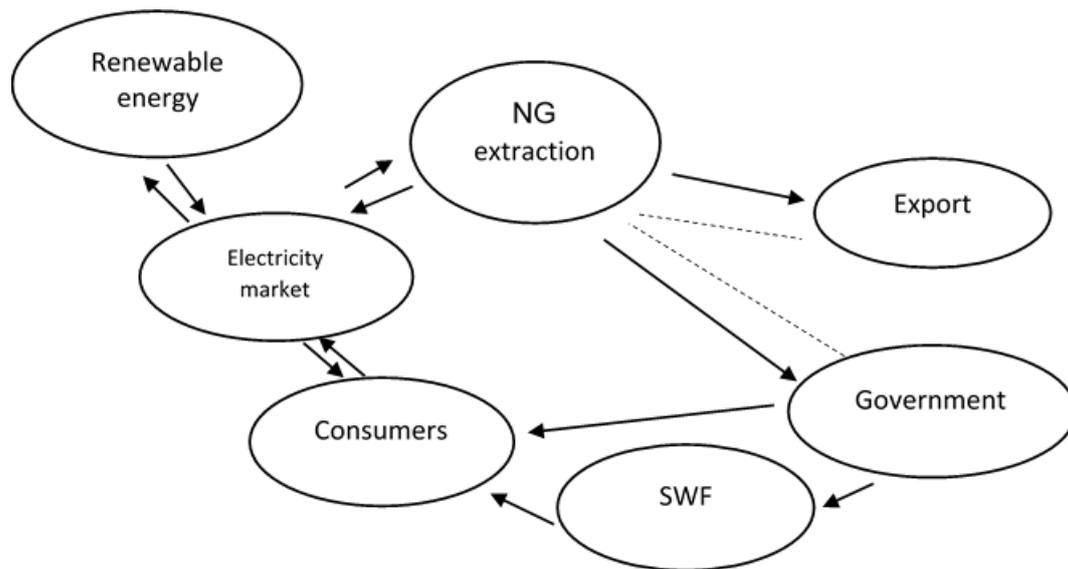
Figure 1. Diagram of the modeled economy.

The exhaustible resource-extraction sector includes firms that extract and transmit the NG to the electricity producers and to export. The directions of the arrows in Figure 1 represent the directions of the transactions; thus, the extraction firms pay taxes to the government, which serves as the regulator and the public trustee. The government transfers a share of the taxation income directly to consumers through the government budget, while the rest is transferred to the SWF. The SWF is invested in assets outside the country, and the rate of return on these investments is also transferred to consumers. The consumers use this money to buy electricity—the only final good in this economy.

In the model, welfare is measured by consumer utility, the value of SWF, and firms' profits. On the other hand, since the electricity-generation firms are owned by individuals, their profits are included in the consumer utility. Next, we provide a mathematical description of the model.

3.1. Electricity Consumers

In terms of consumption, the total domestic supply is assumed to exactly meet demand (market clearing). The current study followed the theory of rational intertemporal choice [42]. As in Agnani et al. [10], we assumed that an individual's consumption is driven by maximization of a utility function, represented by a constant elasticity of intertemporal substitution function (IES), subject to a budget constraint. One basic assumption of this function is that individuals maximize the sum of all their future utilities. The intertemporal elasticity of substitution shows how strongly individuals substitute their current consumption against future one, as a response to a change in the real interest rate. This framework is based on the utility specification, which is used in structural macroeconomic and life-cycle models [47].

At a given time t, individuals live for two periods. In the current model, no population growth is assumed. Thus, the number of consumers is normalized to one in every period, such that in every period there are two individuals representing two generations, one young and one old. Every individual maximizes his or her intertemporal utility U by choosing C_t^y, the consumption during the first period when he or she is young, and C_{t+1}^O, the present value of the consumption during the second period when he or she gets elderly, under the budget constraint.

Let $\beta \geq 0$ be the individual's time preference, as the time discount factor is a measure of the subjective time preference (consumption today vs. consumption in the next period). The consumer's problem, represented as in [10], follows a constant elasticity of the intertemporal substitution function

(in economics with balance-growth paths, we need to assume consumer preferences with constant elasticity of intertemporal substitution, see [47–49]):

$$Max \ U = \ln C_t^y + \beta \ln C_{t+1}^o \tag{1}$$

$$S.t \ C_t^y + \frac{C_{t+1}^o}{1+r} = \Pi_t + \frac{R_t}{2} + \frac{R_{t+1}}{2(1+r)} \tag{2}$$

The left-hand side of the budget constraint represents the present value of an individual's lifetime consumption. The right-hand side is the value of the individual's lifetime income, which consists of the producers' profits from the electricity sector, Π_t, assuming as in Fisher [42] that the production firms are owned by young individuals, the producers' profits are as defined below, and the total governmental transfers are R_t and R_{t+1}. The total transfers in every period R_t are distributed equally among living individuals in that period. Since every period includes two different individuals representing two different generations, the government transfers are equally divided between them. The discount rate, r, is considered exogenous by individual. As in Andersen [43], individuals are forward-looking, so they have knowledge of the total value of all the transfers they will receive during their lifetimes.

The Lagrangian

$\ln C_t^y + \beta \ln C_{t+1}^o - \lambda [C_t^y + \frac{C_{t+1}^o}{1+r} - \Pi_t - \frac{R_t}{2} - \frac{R_{t+1}}{2(1+r)}] = 0$

F.O.C

$\frac{\partial U}{\partial C_t^y} = \frac{1}{C_t^y} - \lambda = 0 \rightarrow \frac{1}{C_t^y} = \lambda \ (i)$

$\frac{\partial U}{\partial C_{t+1}^o} = \frac{\beta}{C_{t+1}^o} - \frac{\lambda}{1+r} = 0 \rightarrow \frac{\beta}{C_{t+1}^o}(1+r) = \lambda \ (ii)$

$\frac{\partial U}{\partial \lambda} = C_t^y + \frac{C_{t+1}^o}{1+r} - \Pi_t - \frac{R_t}{2} - \frac{R_{t+1}}{2(1+r)} = 0 \ (iii)$

$(i) + (ii): C_{t+1}^o = \beta(1+r)C_t^y$
$\tag{3}$

From Equation (3) and Equation (iii) we get:

$$C_t^y + \beta C_t^y = \Pi_t + \frac{R_t}{2} + \frac{R_{t+1}}{2(1+r)}$$
$$C_t^y = \frac{1}{1+\beta}\left(\Pi_t + \frac{R_t}{2} + \frac{R_{t+1}}{2(1+r)}\right) \tag{4}$$

$$C_{t+1}^o = \frac{\beta(1+r)}{1+\beta}\left(\Pi_t + \frac{R_t}{2} + \frac{R_{t+1}}{2(1+r)}\right) \tag{5}$$

Functions (4) and (5) represent the consumption of every individual in each period. The consumption functions of the representative individual are characterized by constant budget shares of total discounted lifetime income, which, in turn, are functions of the total income generated by output production and government transfers to the individual, the real-world interest rate, and the subjective discount rate.

3.2. Exhaustible Natural Resource-Extraction Sector

Assume that the country discovered a certain amount of an exhaustible natural resource, NG, and that it is the country's responsibility to distribute the wealth between current and future generations. Nevertheless, in the Israeli market, a small number of firms have a license for NG extraction, and they act as an oligopoly. For simplicity, the developed model represents perfect competition, but one can easily analyze the model under monopoly or oligopoly.

In the current research, the energy sector is comprised of NG extraction that serves as input to power generation. In general, NG can also be used in the industrial and transportation sectors. However, for the sake of simplicity, we assumed that NG is used only in the electricity sector.

Suppose natural resource-extraction firms choose the amount of resource to be extracted in every period E_t. This is assumed because the economy is initially endowed with an exhaustible natural resource, NG_t, and in each period, the total stock of the resource is determined by the past resource stock *minus* the current resource extraction E_t, so that:

$$NG_{t+1} = NG_t - E_t$$
$$E_t \leq NG_t \ \forall t$$

(6)

E_t is either consumed in the domestic market (E_{Nt}) to produce good X_t or exported (E_{Xt}), such that:

$$E_t = E_{Nt} + E_{Xt}$$

(7)

Assuming competitive markets, the natural resource NG_t price P_t^{NG} is equal in both markets. Extraction firms maximize their profits $\Pi(E_t)$ in each period as follows:

$$Max \ \Pi(E_t) = P_t^{NG} * E_t - TC(E_t)$$

(8)

The parameter $TC(E_t)$ refers to the total cost including the extraction costs, such that:

$$TC(E_t) = F + dt(E_t) + S_t(E_t) + EC_t(E_t)$$

(9)

where F represents the fixed costs; $dt(E_t)$ denotes the government share of the resource wealth that includes income tax and royalties directly transferred to the government budget; $S_t(E_t)$ is the share of taxes that are transferred to a sovereign wealth fund (SWF); and $EC_t(E_t)$ is the variable extraction costs. From first-order conditions:

$$P_t^{NG} = \frac{\partial TC(E_t)}{\partial E_t}$$

(10)

3.3. Government Transfers

Here, the extraction firms are assumed to transfer a share of the NG income to the government, G, in accordance with Israeli regulation.

The current model is based on the assumption that the government transfers some portion of its payments directly to the individual through its yearly budget and that the other portion is transferred to a SWF; $S_t(E_t)$ is the amount that is periodically transferred from extraction firms to the government; and $SWF_t(E_t)$ is the value of the SWF, which is invested overseas.

$R_t(E_t)$ is the periodic governmental transfer to individuals at time t such that:

$$R_t(E_t) = dt_t(E_t) + \varepsilon SWF_t(E_t)$$

(11)

where $dt_t(E_t)$ denotes the direct transfers to the current generation through the government budget, which are finite and limited to the field's lifetime, such that: $\lim_{t \to \infty} dt_t = 0$. ε is the rate of return on the SWF investment. The fund is invested in accordance with national regulations (according to the Israeli Petroleum Profits Tax Law [48], the SWF's assets will be invested outside of Israel, and its goal is to manage the state's income from oil profits via a long-term economic perspective. The purpose is to allocate the fruits of this fund annually to social, economic, and educational goals, and to assist in handling unusual events including environmental events, with negative impacts on the Israeli economy) in Israel.

$$SWF_{t+1}(E_{t+1}) = SWF_t(E_t) + S_t(E_t)$$

(12)

where $dt_t(E_t)$ and $S_t(E_t)$ are functions of E, indicating that government transfers depend on the amounts of gas extracted in every period. These payments are transferred directly from the NG-extraction firms to the government and can be viewed as taxes.

$$\sum_{t=1}^{\infty} \left(\frac{1}{(1+r)}\right)^{t-1} G_t(E_t) = \sum_{t=1}^{\infty} \left(\frac{1}{(1+r)}\right)^{t-1} S_t(E_t) + \sum_{t=1}^{\infty} \left(\frac{1}{(1+r)}\right)^{t-1} dt_t(E_t) \tag{13}$$

Equation (13) implies that the present values of current and future transfers to individuals (the right-hand side of the equation) are equal to the value of the resource wealth, G, which represents the government's share of the total wealth generated from the extracted exhaustible resource. The transfer mechanism is similar to that in Andersen [43], except that in our model, government transfers consist of two components: direct transfers and transfers to individuals through the SWF (indirect), in accordance with Israeli regulation in the NG sector.

3.4. Electricity Producers

In line with Klump and Willman [44], production is defined as a normalized constant elasticity of substitution (CES) function. CES functions make up a key part of energy economy models and are one of the most common aggregate production functions [50]. In addition, GE models are an important application of empirical CES study results [51]. GE models are the most popular models and are commonly CES-based [50,52,53].

We assumed that competitive firms produce a homogeneous good X_t using exhaustible resource E_t, and renewable resource Z_t, with all other factors in the economy fixed. Since we are interested in examining the effect of NG on the economy, we normalized all other factors to unity.

Assume that the exhaustible resource can be used in the domestic market for production: E_{Nt} is the amount used for production of X_t.

Electricity production (X_t) is given by:

$$X_t = \left(\mu^E E_{Nt}{}^{\alpha} + \mu^Z Z_t{}^{\alpha}\right)^{1/\alpha} \quad \alpha = \frac{\sigma-1}{\sigma}, \ \mu^i \geq 0 \tag{14}$$

where $\alpha = \frac{\sigma-1}{\sigma}$ represents the substitution parameter that measures the percentage change in the ratio of two inputs in response to a percentage change in their prices. The function shows that the elasticity of substitution is a constant whose magnitude depends on the value of the parameter σ. Here, Z_t represents the backstop technology (i.e., the renewable energy resource). The parameter μ^i represents the productivity factor of input I (i.e., NG and renewables). Firms are interested in maximizing profits by choosing the amount of input that will be utilized in the production process:

$$Max \ \Pi_t = \left(\mu^E E_{Nt}{}^{\alpha} + \mu^Z Z_t{}^{\alpha}\right)^{1/\alpha} * P_t^E - P_t^{NG} E_{Nt} - P_t^z Z_t \tag{15}$$

where P_t^{NG} is the price of the exhaustible resource (NG); P_t^z is the price of the renewable resource; and P_t^E is the output price (i.e., price of electricity).

The first-order conditions are:

$$\begin{aligned}
&(i) \quad \frac{\partial \Pi_t}{\partial E_{Nt}} = 0: \ \mu^E E_{Nt}^{\alpha-1} \left(\mu^E E_{Nt}^{\alpha} + \mu^Z Z_t^{\alpha}\right)^{1/\alpha-1} P_t^E = P_t^{NG} \\
&(ii) \quad \frac{\partial \Pi_t}{\partial Z_t} = 0: \mu^Z Z_t^{\alpha-1} \left(\mu^E E_{Nt}^{\alpha} + \mu^Z Z_t^{\alpha}\right)^{1/\alpha-1} P_t^E = P_t^Z \\
&(ii)/(i): \ \frac{\mu^E}{\mu^Z} \frac{E_{Nt}^{\alpha-1}}{Z_t^{\alpha-1}} = \frac{P_t^Z}{P_t^{NG}}
\end{aligned} \tag{16}$$

3.5. Renewable Energy Sector

Assume that the price of renewable energy sources is equal to the marginal cost of production and that there are no fixed costs or taxes in this sector, so that revenue equals costs and firms only have

normal profits. We also assumed that renewable energy is used by firms only for power generation. These firms were also owned by young consumers.

3.6. Equilibrium

Market clearing conditions in this class of models refer to the supply of a commodity that must balance demand at equilibrium prices and activity levels.

Thus, the only source of government income is the taxes on the exhaustible resource. When the exhaustible resource is completely depleted, the economic growth is derived by the rate of return on the SWF's investment.

Note that X_t (i.e., electricity) is a nontraded good, meaning that it can be produced and consumed only in the domestic market. We also assumed that

$$C_t = X_t \tag{17}$$

The demand side is the sum of demand from the younger (Equation (4)) and elderly Equation (5); note that Equation (5) is expressed in time $(t + 1)$. To sum the equations, Equation (5) should be expressed in time t so that: $C_t^o = (1 + r)\frac{\beta}{1+\beta}\left(\Pi_{t-1} + \frac{R_{t-1}}{2} + \frac{R_t}{2(1+r)}\right)$ generations:

$$
\begin{aligned}
C_t = C_t^y + C_t^o &= \tfrac{1}{1+\beta}\left[\Pi_t + \tfrac{R_t}{2} + \tfrac{R_{t+1}}{2(1+r)}\right] + \\
&\quad (1+r)\tfrac{\beta}{1+\beta}\left[\Pi_{t-1} + \tfrac{R_{t-1}}{2} + \tfrac{R_t}{2(1+r)}\right]
\end{aligned}
\tag{18}
$$

The supply side is given by Equation (14). That equation and Equation (18) yield:

$$
\left(\mu^E E_{Nt}{}^\alpha + \mu^Z Z_t{}^\alpha\right)^{1/\alpha} = \left\{ \begin{aligned} &\tfrac{1}{1+\beta}\left[\left(P_t^E(\mu^E E_{Nt}{}^\alpha + \mu^Z Z_t{}^\alpha)^{1/\alpha} - P_t^{NG}E_{Nt} - P_t^Z Z_t\right) + \tfrac{R_t}{2} + \tfrac{R_{t+1}}{2(1+r)}\right] + \\ &(1+r)\tfrac{\beta}{1+\beta}\left[\left(P_{t-1}^E(\mu^E E_{Nt-1}{}^\alpha + \mu^Z Z_{t-1}{}^\alpha)^{1/\alpha} - P_{t-1}^{NG}E_{Nt-1} - P_{t-1}^Z Z_{t-1}\right) + \tfrac{R_{t-1}}{2} + \tfrac{R_t}{2(1+r)}\right] \end{aligned} \right\} / P_t^E \tag{19}
$$

To solve this equation, we used the "generalized reduced gradient method" to seek the optimal Z_t to solve the equation:

$$
\left(\mu^E E_{Nt}{}^\alpha + \mu^Z Z_t{}^\alpha\right)^{1/\alpha} = \left\{ \begin{aligned} &\tfrac{1}{1+\beta}\left[\left(P_t^E(\mu^E E_{Nt}{}^\alpha + \mu^Z Z_t{}^\alpha)^{1/\alpha} - P_t^{NG}E_{Nt} - P_t^Z Z_t\right) + \tfrac{R_t}{2} + \tfrac{R_{t+1}}{2(1+r)}\right] + \\ &(1+r)\tfrac{\beta}{1+\beta}\left[\left(P_{t-1}^E(\mu^E E_{Nt-1}{}^\alpha + \mu^Z Z_{t-1}{}^\alpha)^{1/\alpha} - P_{t-1}^{NG}E_{Nt-1} - P_{t-1}^Z Z_{t-1}\right) + \tfrac{R_{t-1}}{2} + \tfrac{R_t}{2(1+r)}\right] \end{aligned} \right\} / P_t^E \tag{20}
$$

For the data assumptions and sources of the other variables $(E_{Nt}, R_t, P_t^E, P_t^{NG}, P_t^Z)$ and the constants $(\gamma, \mu^E, \mu^Z, \alpha, r, \beta)$, see Section 6.1.

This method considers the gradient or slope of the objective function as a change in input values (or decision variables) and determines that an optimum solution has been reached when the partial derivatives equal zero. In this case, the solution to the problem is:

$$
\left[\begin{aligned} &\left(\mu^E E_{Nt}{}^\alpha + \mu^Z Z_t{}^\alpha\right)^{1/\alpha} * P_t^E - \tfrac{1}{1+\beta}\left[\left(P_t^E(\mu^E E_{Nt}{}^\alpha + \mu^Z Z_t{}^\alpha)^{1/\alpha} - P_t^{NG}E_{Nt} - P_t^Z Z_t\right) + \tfrac{R_t}{2} + \tfrac{R_{t+1}}{2(1+r)}\right] + \\ &(1+r)\tfrac{\beta}{1+\beta}\left[\left(P_{t-1}^E(\mu^E E_{Nt-1}{}^\alpha + \mu^Z Z_{t-1}{}^\alpha)^{1/\alpha} - P_{t-1}^{NG}E_{Nt-1} - P_{t-1}^Z Z_{t-1}\right) + \tfrac{R_{t-1}}{2} + \tfrac{R_t}{2(1+r)}\right] \end{aligned} \right]^2 = 0 \tag{21}
$$

We solved this problem by assuming some data for the variable Z_t and minimizing the distance between our prediction and the actual solution of Equation (20) based on the actual data.

4. Natural Gas in Israel

Up until the past decade, Israel was considered a resource-deprived country, especially regarding fossil fuels [40]. However, in the last two decades, the country began using NG as a primary energy source. Israel's first significant offshore reserve of NG was discovered in 1999. A decade later, major discoveries were made at the Tamar and Leviathan. Together, the proven reserves contain about

900 billion cubic meters (BCM), while the annual domestic consumption in Israel is estimated at about 12 BCM. Major public investments in the transmission infrastructure are projected to double the demand.

Policymakers and the public in Israel have raised many questions regarding the optimal policy for developing and managing the NG discoveries. Such questions have also been tackled by other countries. The basic question refers to whether to exploit the gas or to hoard it. Other questions are related to government management of its share of revenues, the optimal sector structure, and export strategy. Deciding what proportion of the NG reserves should be preserved for domestic needs and how much should be exported is a particularly complex issue. On one hand, NG exports are expected to enrich the government's take, which could then be invested in channels that can lead to economic growth. For example, investments in promoting R&D in renewable energies to increase technological efficiency, improve storage technologies, and the like can in the long run provide a substitute for NG. On the other hand, the Israeli economy can enjoy the benefits of transitioning to NG in terms of energy security and cleaner (than coal) power generation by maintaining a large reserve of gas, which will serve as a stimulus for the transition.

Hence, comprehensive analyses are needed to determine the best policy for these resources that will ensure long-term sustainable economic growth. Such a policy must delineate the rate of resource extraction and allocation among generations, the taxation scheme, and government revenues to utilize the resource's value. Detailed policy analysis is essential for countries in which exhaustible resources have recently been discovered such as Israel.

5. Extraction Scenarios

In this section, a numerical simulation of the model is provided for the Israeli NG sector across three scenarios considered by the stakeholders about NG management. Following Andersen [43], we defined one period as 25 years, starting from 2015. In every period, two generations were present. The model was applied for three periods.

When applying the model, actual market data for the years 2014–2017 were used. In the baseline scenario, the data for the following years (2018–2065) were based on the financial statements of NG-extraction firms in Israel as of 30 December 2017.

The baseline scenario was based on actual Israeli market regulation, which allows for the export of 40% of the total NG amounts. In this scenario, the NG will be completely depleted by 2065 (i.e., in the second period of the model), which means three generations (note that in every period, two generations are alive: one young and one old). The young people from the first period will become the old people in the second period, and a new generation will be born, making three generations in total that will benefit directly from the NG windfall.

The conservative scenario assumes a lower extraction rate, as the demand for NG originates solely from domestic use. This scenario simulates the public desire to preserve the NG solely for domestic use in accordance with "strong sustainability criteria" that call for permanent minimal stock reserved for future generations [54]. Therefore, no export is assumed. In this scenario, the NG is projected to be depleted by 2090, while supplying input for electricity production for five generations (in the three periods 2015–2040, 2041–2066, and 2067–2090). We begin with the young and old generations in the first period. The young generation from the first period will become the old generation in the second period, and a new generation is born. In the third period, the young generation in the second period becomes the old generation, and a new generation is born.

The intensive scenario assumes a higher extraction rate due to high demand in both domestic and export markets. Only the generations in the first period (two generations) can use NG for electricity generation until 2040. Any amount slated for export is assumed to be bought on the international market. NG-extraction firms are assumed to pay the same share of taxes (adjusted to the extracted amount of NG) in the three scenarios. Table 2 summarizes the data assumptions and sources. Figure 2 shows the amount of exported NG in the different scenarios.

Table 2. Data assumptions and sources across the three scenarios.

Assumptions	Baseline Scenario	Conservative Scenario	Intensive Scenario
Export	Export of 9 BCM from 2020 to 2045, 5 BCM until 2059, and 2 BCM until field depletion in 2065, calculated based on Delek Drilling Financial Statements (2017) [55]	No export	Export of 20.24 BCM from 2020–2040. In this scenario, domestic NG use is equal to that in the baseline scenario. The excess amount of NG is destined for export and is distributed equally across the period 2020 to 2040.
Depletion	Tamar projected depletion by 2050. The other fields supply NG until 2065.	The NG will be depleted by 2090, calculated based [55]. Tamar field will be depleted by 2050, calculated based on Delek Drilling Financial Statements (2017) [55] NG-extraction amounts are similar to the baseline scenario for 2015–2065. The amounts are distributed equally across the years.	All NG reserves are depleted by 2040. NG-extraction amounts are similar to the baseline scenario for the years 2015–2040 in the domestic market. The rest is exported.
Financial data	Data on annual NG extraction, firm incomes, costs, royalties, government share of royalties, levy, income taxes, and corporate taxes are based on Delek Drilling Financial Statements (2017) [55].	Data on firm incomes and levies are similar to the baseline scenario until 2050. For 2051–2090, the data equal the average over the 5 years before the specific year; for example, income tax in 2051 equals average annual income tax for 2044–2049.	Data on annual NG extraction, firm incomes, costs, royalties, government share of royalties, levy, income taxes, and corporate taxes are based on Delek Drilling Financial Statements (2017) [55].
Levy	The levy is imposed on profits derived from the sale of NG pursuant to the Israeli Petroleum Profits Tax Law [56]. The levy follows a progressive R-Factor-based tax [1] starting at 20% and increasing to about 45%. The government take from the levy is transferred to the SWF.		
Corporate tax	10% corporate tax in accordance with the Israeli Petroleum Profits Tax Law [56] and the Ministry of environmental protection [57]. The income taxes are transferred to the government budget.		
Royalties	Royalties of 24% of total cash flow; the government share of royalties is 11.5%, in accordance with the Sheshinski Committee [58] and the Israeli Petroleum Profits Tax Law [56]. The royalties are also transferred to the government budget.		
Rate of return on SWF Investment (Same for all the scenarios)	3% rate of return on SWF investment, based on Bank of Israel [59], who found that rates of return on investments vary between 1% and 5%. In the benchmark scenario, we assumed 3% and then we conducted a sensitivity analysis to see how changing this assumption might change the results.		
Transfers to individuals (Same for all the scenarios)	The government transfers 3.5% of the SWF accumulated capital to the public between 2020 and 2034; in the following years, the government transfers an amount equal to the average rate of return for the previous 10 years multiplied by the accumulated capital, in accordance with the SWF Law of 2014. 3% rate of return on SWF investment.		

[1] A complex formula considering the ratio between accumulated income and accumulated investments.

Figure 3 hereafter shows that in the first period, NG usage was higher under the intensive scenario than under the baseline and conservative scenarios, and reached zero when the total gas amounts were depleted in 2040. In the baseline scenario, the domestic use of NG was less than in the conservative scenario due to the export amounts under the baseline scenario. However, the total extracted amount over the resource lifetime in the baseline scenario was equal to that in the conservative and intensive scenarios.
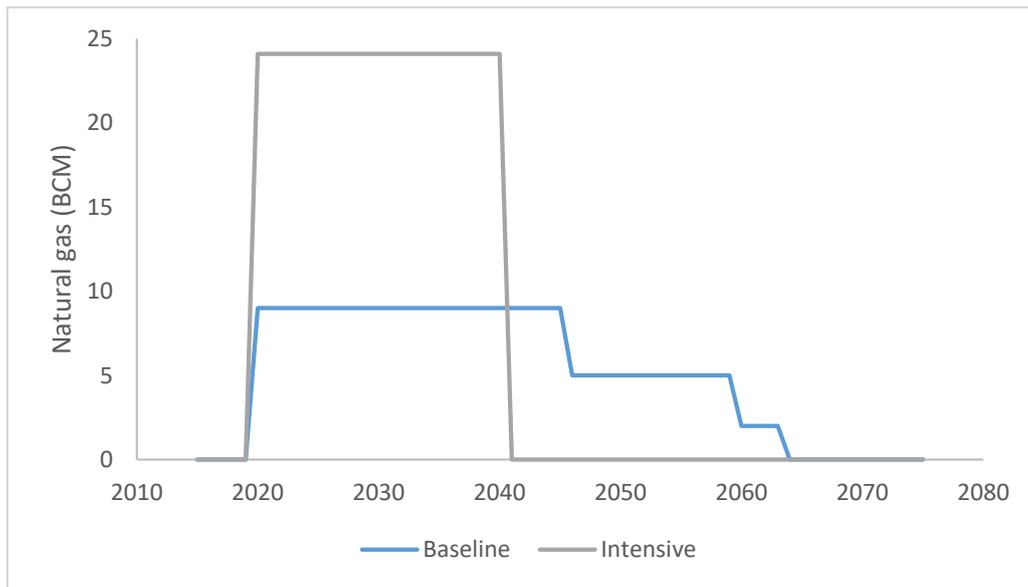
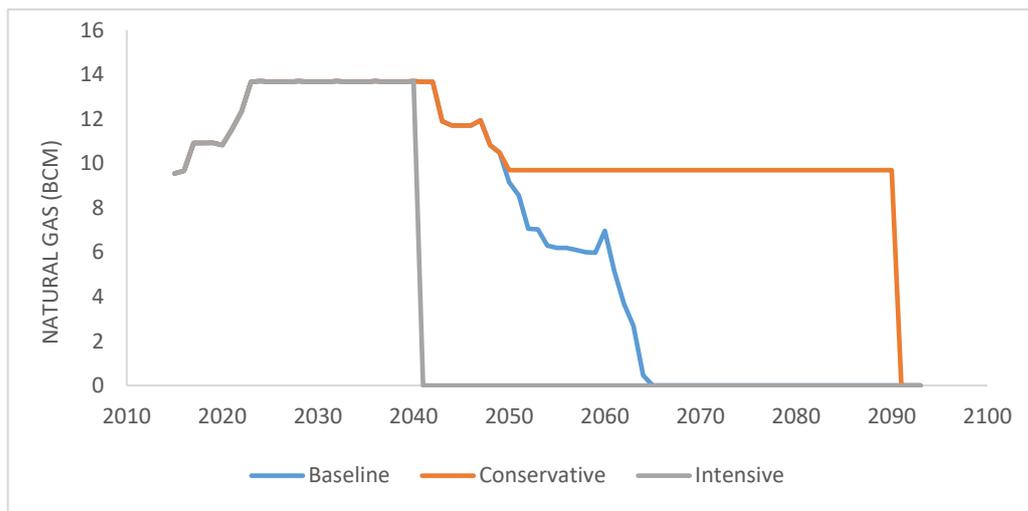**Figure 2.** Natural gas (NG) export amounts for the baseline and intensive scenarios.

Figure 3. Domestic use of NG for electricity generation under the three scenarios.

6. Results

6.1. Simulation Results

Table 3 describes the data and sources for the model parameters:

Table 3. Parameter values and sources in the three scenarios.

Parameter	Description	Data Source	Range for Sensitivity Analysis
$P_t^{NG} = 5.7\$/MMBTU$	Cost of electricity generation by NG	[59]	$4.5–6.7/MMBTU
$P_t^{Z} = 0.0625\$/kWh$	Cost of electricity generation by renewable energy	[59]	
$P_t^{E} = 0.14\$/MMBTU$	Electricity tariff	[60]	
$\alpha = 0.6$ [1]	The substitution parameter measures the percent change in the ratio of two inputs used in response to a percent change in their prices	[61]	
$\beta = 0.015$	Individuals' subjective discount rate	[62,63]	0–0.045
$r = 2.5\%$	Annual discount rate	[57,64]	1.5–4.5%
$\mu^E = 60\%$	Productivity factor of NG	[65]	
$\mu^Z = 20\%$	Productivity factor of renewable energy sources	[43]	See extension 1 in Section 5

[1] Kander and Stern [61] examined the role of substitution from traditional to modern energy using a constant elasticity of substitution production function (SEC). According to the authors, as the share of modern fuels is initially very small, while other fuels (coal and firewood in the stated model) can often be used for the same applications, it is likely that the substitution factor is higher than 1, so that neither fuel is essential. The authors estimated this factor to be about 4.4. In our model, we assumed $\sigma = 2.5$ (i.e., $= 0.6$). This value reflects high flexibility, meaning that NG can be easily substituted by renewable energy and vice versa.

Figure 4 depicts the NG-extraction firm profits. In the first period, profits were higher for the intensive scenario than for the baseline and conservative scenarios. In the second period, profits were higher in the conservative scenario. The decline in profits was due to the depletion of the NG fields. In the intensive scenario, the deposits will be depleted by 2040. In the baseline scenario, they will be depleted by 2065, and in the conservative scenario, by 2090.
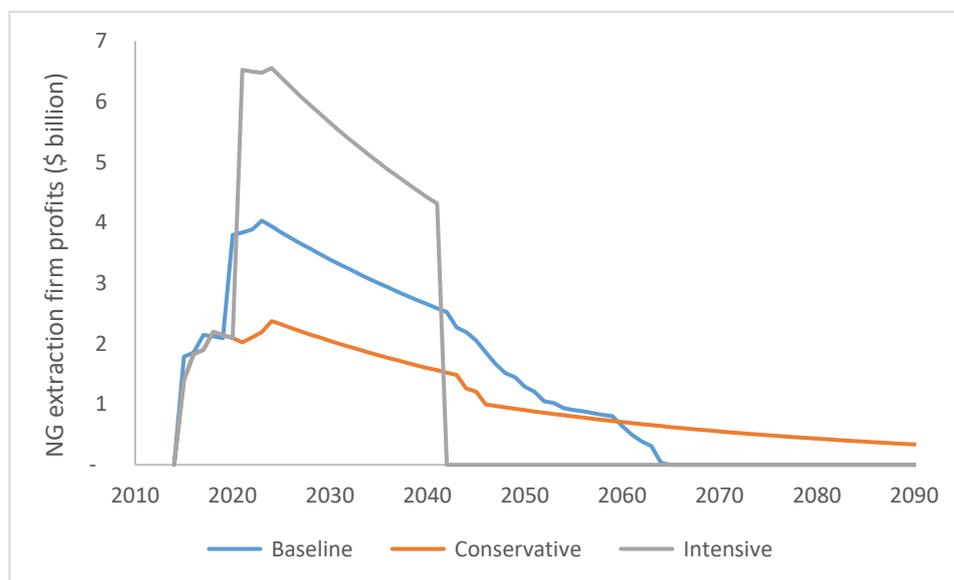
**Figure 4.** NG-extraction firm profits under the three scenarios.

Government transfers refer to the implementation of an income transfer policy, as defined in Equation (11), with respect to Israeli regulation regarding NG wealth distribution. These transfers depend on NG-extraction amounts and NG prices. Table 4 describes the government take during the lifetimes of the fields under the different scenarios. The government take includes income tax, royalties, and levy paid by the NG-extraction firms.

Table 4. Government take during the lifetime of the NG fields in the different scenarios, in 2018 prices.

	Baseline	Intensive	Conservative
Period	2015–2065	2015–2040	2015–2090
Total income ($ billion)	62.55	72.38	44.88

The calculations in Table 4 are shown in present values, at a 2.5% discount rate, following the Ministry of Environmental Protection [57] and Li and Pizer [64]. They include the periodic government income without the SWF accumulation. As can be seen in the table, the government income in the first period will be higher in the intensive scenario than in the baseline and conservative scenarios due to higher NG extracted amounts and will decrease to 0 at a higher rate when the NG is totally depleted.

Figure 5 describes the SWF accumulation. It shows the aggregate level of the SWF at the end of every year t, starting in 2020, the year in which the NG-extraction firms are expected to start paying the levy.
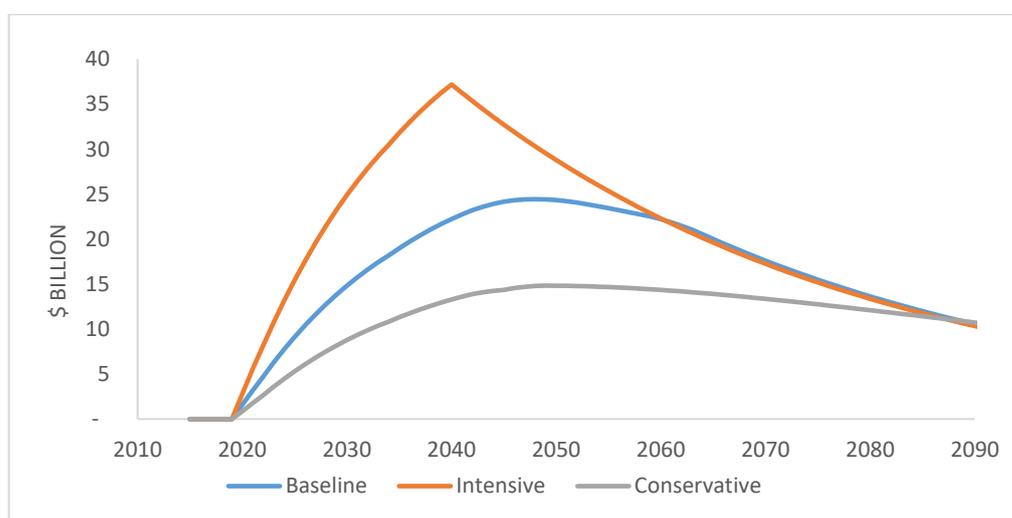
Figure 5. Growth in sovereign wealth fund (SWF) value under the three scenarios in the benchmark scenario.

As can be seen in Figure 5, the value of the SWF was 31% higher in the intensive scenario than in the baseline scenario and 64% higher than in the conservative scenario. Note that in the first period, the SWF value grows exponentially due to the increase in government transfers to the SWF, which were generated from the levy. When the NG is depleted, the only source for the SWF value is the rate of return on its investments. Thus, the growth rate is more moderate.

The government transfers are also higher in the intensive scenario. These transfers include income tax and royalties, which are transferred directly through the yearly budget and through a portion of the rate of return on SWF investments. A 3% return on investments for the SWF was assumed. Note that this fund is infinite, and thus the transfers to individuals are also infinite. Table 5 provides the results for the four periods.

As seen in Table 5, the total transfers to individuals were higher under the intensive scenario. This is true except for the second and third periods, when the NG is totally depleted under the intensive scenario, so the only source for government transfers is the rate of return on the investment of SWF. In the fourth period, when the NG is depleted across all three scenarios, the transfers are equal. In addition, the first generations receive higher transfers under the intensive scenario. In the second period when the NG is totally depleted under the intensive scenario, the transfers are higher under the baseline scenario.

Table 5. Total government income transferred to individuals ($ billion).

Year	Baseline	Intensive	Conservative
2015–2040	23	36	14
2041–2065	25	23	16
2066–2090	12	11	11
2090–2115	6	6	7
Total	66	76	48

The model results also showed that the intergenerational (three generations) utility was higher under the intensive scenario than under the baseline scenario or under the conservative scenario. The utility was higher in the first period in all three scenarios, and it decreased gradually due to NG depletion in the second period. The welfare gained from NG by scenario is depicted in Table 6.

Table 6. Welfare gained from NG by three generations, according to the three scenarios.

Source	Baseline	Intensive	Conservative
Net benefit ($ billion) [1]	1194.7	1367.8	948.5
SWF value ($ billion)	124	153	85
Total ($ billion)	1318.7	1520.8	1033.5

[1] Measured by consumer utility and firms' profits.

In the long run, in the first period, the economic surplus in the intensive scenario was higher than in the baseline or conservative scenarios. The results indicate that a higher extraction rate combined with an appropriate investment strategy is better than a conservative extraction rate. This result is consistent with the literature (see, for example, [14,30]).

6.2. Simulation Results—Investing SWF in Improving Renewable Energy Productivity

Next, the model was extended by assuming that the government transfers a share of the tax income from NG directly to individuals, while the rest is invested in R&D aimed at increasing renewable energy production. Examples of this type of policy are public investments in energy storage facilities or in energy-efficient technologies (renewable energy usually depends on external factors such as weather conditions, and is therefore considered less secure than fossil fuels).

The results remain robust, indicating that the welfare gain is higher in the intensive scenario. The results also showed a small improvement in utility levels under the three scenarios compared to the utility levels in the benchmark scenario (note that we assumed that only the rate of return on the SWF investments is transferred to the individuals; thus the fund itself still exists): 0.8% in the intensive scenario, 1% in the baseline scenario, and 1.2% in the conservative scenario. Therefore, an increase in the productivity of renewable energy projects leads to an increase in electricity production and consumer utility, followed by an increase in economic welfare. Investing the SWF returns in R&D, which leads to improved productivity of renewable energy projects, may, under some conditions, be more beneficial than direct income transfer.

This result is consistent with Hartwick's weak sustainability rule stating that to offset declining stocks of exhaustible resources, public investment in reproducible capital is essential [14,27–30]. In addition, our results reconfirm the basic result of Solow [13] that technological progress including scientific and engineering processes and R&D is a key factor in long-term sustainable economic growth.

7. Discussion

The results of the current study suggest some answers to the basic questions that were raised when the NG reserves were discovered in Israel such as preferred extraction rate and export strategy.

These questions are relevant not only to Israel, but also to countries that seek to manage their windfalls objectively.

This research was motivated by growing concerns about the availability of exhaustible natural resource reserves in general, and NG in particular, not only for the current generation but also for future ones. Policymakers are required to define a comprehensive management strategy to find economic growth engines and overcome economic degradation. Starting from the intertemporal choice model by Fisher [42], the characteristics necessary were added for exhaustible natural resource management, adopted from Agnani et al., Andersen, and Klump and Willman [10,43,44]. The model was applied to the Israeli NG sector. The advantages of the model developed above are: (1) it enables the examination of the intergenerational interactions and the effects of different variables on the economic welfare; (2) it allows for a comparison of different extraction scenarios and evaluation of the economic indicators emerging from different assumptions; and (3) it makes it possible to examine the interaction between different players in the energy economy (NG-extraction firms, electricity generation firms, the government and the consumers). This model can be used as a tool to define a sustainable policy that considers the welfare of current as well as future generations.

The results of application to the Israeli case indicate that in this small open economy that was recently endowed with a windfall of NG, a higher NG-extraction rate combined with an appropriate investment strategy for NG profits is economically preferable. This result was determined with respect to consumer utility, producer profits, and government transfers to the public. The results also indicate that government income as well as the accumulated value of the SWF are higher in the intensive scenario. Transfers to individuals are also higher in the intensive scenario. This means that investing the income from an exhaustible resource can offset the decrease in welfare due to exhaustion of the resource. The result is consistent with the literature [14,30]. However, it is contrary to Nyambuu and Semmler [24], who suggested that fossil fuel resources should not be depleted within a short time horizon. However, the researchers did not include the usage of alternative, renewable, energy sources that can substitute perfectly in producing energy in the long run.

Furthermore, the results indicate that investment of returns from the SWF into R&D on renewable electricity production is also essential for sustainable economic growth. Investing returns from the SWF in renewable electricity production projects will lead to economic growth as well as help build new energy sources for future generations. This result is timely and highly important, as the world's transition to clean energy is only a matter of time. Countries are rapidly shifting to energy sources that emit less pollution. Substituting coal with NG could be a mid-term solution for Israel until the country transitions to renewable energy.

The results of the current study are especially important today as nations pursue the transition to less carbon-intensive energy sources. However, these results must be combined with a comprehensive strategic analysis of the impact of this policy on the different sectors. In addition, they must take into account considerations such as energy-efficiency aspects, strategic and geopolitical issues, energy security, and environmental effects.

The findings of this research have important policy implications. Policymakers should be aware of the demand for exhaustible resources, which are an essential source of energy production. Choosing an appropriate investment strategy for the SWF is important, as such a strategy can help to avoid economic degradation resulting from depletion of the exhaustible resource.

8. Conclusions

Natural resources including NG belong to the public and should be utilized to raise the public's welfare and well-being. Moreover, decisions made by policymakers today will affect the welfare of the current and coming generations. Policy goals should be defined and prioritized, and management strategies should be set concerning these goals.

In the last decade, the number of countries where natural resources including NG have been discovered has grown rapidly. The Israeli experience and the proposed model can be used in

formulating a strategy for managing NG resources. The model proposed in the current paper can serve as a tool for other countries with newly discovered exhaustible resources that seek to identify resource management strategies and to choose the most appropriate policy to achieve their goals.

It is important to emphasize that this research was carried out independently and was not funded by any external body, making it objective and independent. Thus, the findings of this research can help policymakers assess and adjust their activities in the energy sector and consolidate a management strategy for the NG sector, which can also be applied to other sectors and other exhaustible resources. Finally, the current study is one of the first attempts to evaluate intergenerational welfare from NG reserves. A follow-up investigation is required to continue the rigorous assessment of the economic impacts of NG reserves on the Israeli economy and society.

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