Energy Policy 154 (2021) 112325

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

A petroleum upstream production sharing contract with investments in renewable energy: The case of Lebanon

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ARTICLE INFO

Keywords:
Production sharing contract
Renewable energy
Oil & gas
Energy transition
Optimization model

ABSTRACT

Developing countries endowed with petroleum resources face various challenges in balancing their economic development needs and their contribution to combating climate change. They aim at increasing their reliance on renewable energy; however, they are faced with regulatory, financial, technical, and knowledge-related barriers. Many oil and gas companies started to transition from their core business in oil and gas to the wider energy field. In this paper, we show how the most common contractual arrangement between developing countries and oil and gas companies - the Production Sharing Contract (PSC) - can be modified to include renewable energy elements. We introduce a Renewable Contribution parameter that defines the share of the company profit petroleum that should be re-invested in renewable energy in the host country and we develop an optimization model that defines the state objective function and constraints. We apply the modified PSC to the case of Lebanon after populating various oil and gas and renewable energy scenarios. We show that a limited Renewable Contribution of 10% can provide a large share of the investment needs of the renewable energy sector and can contribute to emission reduction, economic development and job creation while providing companies with attractive economic incentives.

1. Introduction

Climate change is a major challenge facing humanity and global economic development (Sadorsky (2012); Foster et al. (2017)). Developing countries, in particular, have the greatest difficulties to adapt to this challenge. Millner and Dietz (2015) highlight three main reasons for these difficulties as follows: the geography of developing countries is more prone to climate change; they rely on sectors that are more sensitive to climate change; and they lack adaptive capacity in terms of financial resource, good governance, infrastructure and information. At the same time, developing countries face conflicting needs for poverty reduction and economic development that are mostly driven by traditional development strategies and the usage of their primary resources on one hand, and the requirement to adapt their policies to the dangers of climate change on the other hand.

Renewable energy is one of the most important adaptation tools to reduce the effects of climate change. Renewable energy targets are now available in 124 developing and emerging countries (UNEP (2017)). The fast implementation of renewable energy projects in developing countries is expected to create a positive impact on economic development enabled by a healthy energy sector that attracts investments (IRENA (2018)). Unfortunately, the upscale of renewables in developing markets faces several regulatory, commercial, technical, and institutional barriers (Haas et al. (2018), Karatayev et al. (2016); Yaqoot et al. (2016); Khoury et al. (2016); Kinab and Elkhoury (2012); Shahsavari and Akbari (2018)). The following four main common themes seem to resonate in the literature: 1) the lack of a clear regulatory framework and good governance principles, 2) high political, legal and commercial risks which hinder access to finance, 3) difficulties in securing long term power purchase agreements under a vertically integrated electricity market architecture and subsidized electricity tariffs, and finally 4) barriers in developing the local expertise to establish a sustainable and healthy renewable energy sector.

In parallel, the landscape of the energy sector is undergoing some unprecedented structural changes: The first quarter of 2020 witnessed for the first time foreign direct investments in renewable energy exceeding those in the oil and gas sector (IRENA (2020a)). BP, an established oil and gas company (OGC), projects that peak oil demand has either been reached or will be reached very soon (BP (2020a)). The economics of renewable energy projects are continuously improving

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https://doi.org/10.1016/j.enpol.2021.112325
Received 1 May 2020; Received in revised form 15 April 2021; Accepted 17 April 2021
Available online 30 April 2021

while oil and gas projects suffer from high price risks (Hamie et al. (2018)). Renewable projects can be more economic than some upstream projects that have relatively low and uncertain returns and high project execution risks (WoodMackenzie (2017)). This evolving environment, in addition to sustainability concerns, has driven many major OGCs to consider renewable energy as a core element of their strategy for the future (Pickl (2019)): European companies in particular are re-positioning themselves as energy companies and are building core expertise in selected areas of the renewable energy spectrum.

Therefore, there seems to be a common goal between developing countries endowed with petroleum resources and many OGCs in undertaking a diversification toward renewable energy while still focusing on the exploitation of petroleum resources. Developing countries are in need of capable companies that have proven experience in dealing with the investment barriers typically faced in similar environments and OGCs interested in the energy transition can find suitable ground for diversification in these developing countries taking the petroleum sector as a starting point for that. This common goal has not yet triggered any changes to the contractual agreement between developing countries and OGCs to enable a win-win collaboration in their common efforts to increase their investments in renewable energy.

To the best of our knowledge, this paper proposes for the first time a modified upstream oil and gas contract that incorporates renewable energy elements within it. In the upstream oil and gas sector, production sharing contracts (PSCs) are among the most common types of contractual arrangements (Bindemann (1999)) especially in developing countries (Allen&Overy (2013)). This paper investigates how the terms of the PSC can be modified to benefit from the common perceived goal of diversifying toward renewables for developing countries engaged or planning to exploit petroleum resources and oil and gas companies. We introduce a new parameter to the PSC called Renewable Contribution (*RC*). *RC* defines the share of the private company profit petroleum that should be re-invested in renewable projects in the country while still being owned by the private company. We describe the dynamics of the PSC-RC system including the formulation of an optimization problem that quantifies the state objective function and constraints. We apply the PSC-RC system to the case of Lebanon, a country in the Eastern Mediterranean region that started to conduct exploration activities in its promising offshore and that aims at increasing the share of renewable energy in the energy mix to 30% by 2030 (MEW (2019)). We analyze and illustrate the effects of the introduction of *RC* on the availability of funding for renewable projects, the reduction of emissions, and on the profitability of oil and gas companies under different oil and gas and renewable energy scenarios. We then discuss and present the policy implications.

The rest of this paper is organized as follows: Section 2 discusses background information about the relation between OGCs and renewable energy and about the taxation of the petroleum sector. Section 3 describes how PSCs are generally designed and Section 4 presents the PSC-RC system. Section 5 details the Lebanese case study, while Section 6 shows the results of the application of the PSC-RC system on the Lebanese case. Finally, Section 7 concludes and provides the main policy implications.

2. Background

Two background topics are of particular relevance to the scope of this paper: 1) the relation between OGCs and renewable energy and 2) the way petroleum resources are generally taxed.

2.1. The oil and gas companies and renewable energy

OGCs are facing a hard strategic decision: embarking in the energy transition to low-carbon technologies or focusing on maximizing value from their existing petroleum assets (Fattouh et al. (2019)). Choosing the energy transition path includes shifting their focus from oil to natural gas as a cleaner source of energy, replacing a share of their fossil fuel business by renewable energy investments and extending their primary energy business to the electricity sector where linkages with gas-fired or renewable electricity generation are possible (Lu et al. (2019)).

Hartmann et al. (2020) argue that two country-specific and two firm-specific factors affect the positioning of the oil and gas companies toward this transformation: the regulative and normative social pressures in their home-countries, and the environmental citizenship and level of internationalization of the company. Green et al. (2020) study the evolution of the behavior of major OGCs from 2004 to 2019 and classify their political and business strategies towards climate change: Firms are positioned as either resisting the transition (Chevron, ExxonMobil, Eni), or hedging it (Equinor, Shell, BP, Total). Focusing on the eight majors[1] in the upstream oil and gas sector an Atlantic rift seems to exist in their attitude toward energy transition (Pickl (2019)): European majors are leading in articulating and implementing renewable energy strategies with considerable financial investments while American companies are lagging behind and remain mainly focused on improving the efficiency of their hydrocarbons business. This can include introducing renewable energy into their hydrocarbon production operations for cost reduction purposes (Ericson et al. (2019)).

Yet, as of 2020, with the ongoing Covid-19 pandemic, the historical crash in oil prices and the improved competitiveness of renewable energy technologies, European majors are more than ever walking the talk toward this transition and are aiming to become leaders in the renewable energy sector. They are acquiring and integrating dedicated renewable energy arms and are accumulating experience in selected areas of the renewable spectrum that better fit their existing experience and their views of the future (Table 1). Additional details are provided in Appendix A.

2.2. Petroleum taxation

The petroleum sector possesses several characteristics that affect the way it is taxed. Boadway and Keen (2009) discuss how 1) the high sunk costs, 2) the potentiality for substantial rents and substantial tax returns, 3) the various uncertainties involved, whether geological or related to prices and policies, 4) the asymmetry of information that exists between OGCs and governments and 5) the international considerations that come into place are specific to this sector. When designing its petroleum fiscal regime, the government wants to maximize revenue from the extraction of its resources while providing sufficient incentives to foreign investors (Bindemann (1999)). Theoretically, the fiscal regime should aim to be flexible, neutral and stable (Tordo (2007)): a flexible system provides the state with adequate share of economic rent under different conditions (where "economic rent is the amount by which the payment received in return for some action exceeds the minimum required for it to be undertaken" (Tordo (2007))); a neutral system results in economic efficiency such that overinvestments and underinvestments are both discouraged and a stable system is one that is predictable over a long period of time. While taxing economic rents can be neutral from economic theory point of view, designing such tax systems is very challenging due to the various particularities of the sector (Lund (2009)).

Two broad categories of agreement between governments and OGCs exist: concessionary systems and contractual systems (Nakhle (2008)). In concessionary systems, the ownership of the petroleum resources shifts to the OGC at the well head. The OGC then pays the state royalties and taxes in return for the exclusive rights it is given to explore and produce in a delimited area (Nakhle (2008)). Under contractual systems, the state retains the ownership of resources and the investor owns its share of production only at the delivery point (Tordo (2007)). A PSC is

[1] BP, Chevron, Equinor, Eni, ExxonMobil, Petrobras, Shell, Total.

Table 1
Summary of European Majors positioning toward renewable energy - adapted from (BP (2020c); Total (2020a); Benezet (2020); Equinor (2020a); Eni (2020b); Shell (2018); Shell (2020a)), RE refers to renewable energy and PV to photovoltaic.

Company	Positioning	Current RE Capacity	RE Targets	Main RE Technologies	RE Investments
BP	"From international oil company to integrated energy company"	2.5 GW	50 GW by 2030	Solar PV, Onshore/ Offshore Wind, Biofuel	5 Billion USD/ year by 2030
Total	"Transforming Total into a broad energy company"	6 GW	25 GW by 2025, RE to constitute 40% of company portfolio by 2050	Solar PV, Onshore/ Offshore Wind, Batteries	1.5 Billion USD/ year by 2025
Equinor	"Equinor is an international energy company committed to longterm value creation in a low carbon future inspired by its vision of shaping the future of energy.", "Becoming a global offshore wind major"	0.5 GW	4–6 GW by 2026	Offshore Wind, Solar PV	2 to 3 Billion USD/ year by 2023
Eni	"We are an Energy Company", "Leader in the energy transition"	0.25 GW	5 GW by 2025, 15 GW by 2030, >55 GW by 2050	Solar PV, Wind	NA
Shell	"Shell intends to thrive as the world transitions to lower-carbon energy"	Few hundred MW	NA	Solar PV, Wind, Batteries	1-2 Billion USD/ year

one form of contractual system where the state enters into an agreement with an OGC granting it the exclusive right to explore and produce petroleum in a defined area such that the OGC bears the entire financial and non-financial risks of the project (Allen&Overy (2013)). If commercial discoveries are made, the OGC is entitled to recover its costs and make additional profits only when the production phase is reached, otherwise, the OGC receives nothing (Brady et al. (2011)). PSCs are inefficient contract forms from economic theory point of view. They are predominantly used in the petroleum sector because they offer an efficient arrangement for institutional risk sharing between the state and the OGC (Bindemann (1999)).

Empirical literature employs specific indicators to assess mineral tax systems: For governments, the indicators include the government revenues and the average effective tax rate; while for private companies, the internal rate of return (IRR), the payback period and the breakeven prices among others provide indicators for profitability and neutrality (Laporte and de Quatrebarbes (2015)). The optimization model that we present uses the company IRR and the state revenues among other indicators of value.

Optimization models are one of the main employed methods to support decision-making in the oil and gas sector in relation to optimal investment decisions, extraction rates or timing of abandonment (Shafiee et al. (2019)). The Discounted Cash Flow (DCF) analysis is the most used approach to calculate the net present value of a project from the state or the company points of view (Smith (2013)). Scenario-based approaches for evaluating tax policies in the oil and gas sector are frequently used to compare the performance of tax regimes (Smith (2013); Johnston (2003); Van Meurs (2016)). This paper employs the DCF approach and tests the PSC-RC system over a set of 27 scenarios covering the upstream oil and gas and the renewable energy sectors in Lebanon.

Concerning the Lebanese PSC, Maddah et al. (2014) present an optimization model that determines the parameters of a PSC while identifying how the state share of natural gas can be best used. Yet, the proposed model does not consider variable state share of profit petroleum or specific details in tax calculation such as indefinite loss carry-forward. Yassine et al. (2013) perform a statistical analysis on typical PSC parameters and provide recommendations for the formulation of the Lebanese PSC.

This paper provides the following contributions:

- To the best of our knowledge, this paper presents for the first time an upstream oil and gas contract that contains renewable energy elements within it (PSC-RC) and discusses the related policy implications.
- We formulate the associated optimization model that quantifies the state objective function and constraints and we apply it to the Lebanese case after populating various realistic scenarios for the upstream oil and gas and renewable energy sectors in Lebanon.
- The proposed optimization model contains, to the best of our knowledge, the most accurate representation to date of the details of the existing Lebanese PSC including variable state share of profit petroleum and indefinite loss carry-forward.

3. Designing a PSC

A PSC is generally composed of four main elements that are computed on a periodic basis (Bindemann (1999); Allen&Overy (2013)) (Fig. 1):

- Royalty: Once production starts, the OGC delivers a share of the gross production to the state. This share is called royalty. Royalty can be set to 0.
- Cost petroleum (or oil): The remaining petroleum after deducting royalty is termed "disposable petroleum". Cost petroleum is the share of the disposable petroleum that is delivered to the OGC to recover its capital and operational expenditures. Generally, this share is capped by a cost petroleum ceiling below 100% so that the state can still generate some returns in the early years of production.
- Profit petroleum (or oil): The remaining petroleum after deducting royalty and cost petroleum is called profit petroleum. The profit petroleum is divided between the OGC and the state according to a certain percentage. It is common that this percentage be fixed or variable with prices, production volumes, costs, or company returns.
- Income tax: The OGC will then pay income tax on its revenues composed of the cost petroleum and the profit petroleum after accounting for depreciation. Sometimes, this tax is covered by the state on behalf of the OGC.

When designing a PSC, the state has to first decide which parameters of the PSC will be incorporated into the system. The state then should decide which parameters should be fixed and which remain open for bidding or negotiation. These decisions are tackled while the state possesses limited information about the potential size of the petroleum deposits, their chemical composition, the costs of extracting them and the prices of oil or gas at the time of extraction. Additionally, the state strives to maximize its share of the production but should offer terms that are attractive enough to OGCs to accept the associated exploration risks (Sunley et al. (2003)). Given the uncertainties involved, anticipating the returns from a certain petroleum asset is not a straightforward task to the government (Tordo (2007)). Auctions or bidding offer a way to discover the best terms of the PSC that the state can get given the underlying uncertainties and the information asymmetry with the OGCs (Boadway and Keen (2009)).

The tables in Appendix C.4 describe the notation used and list the

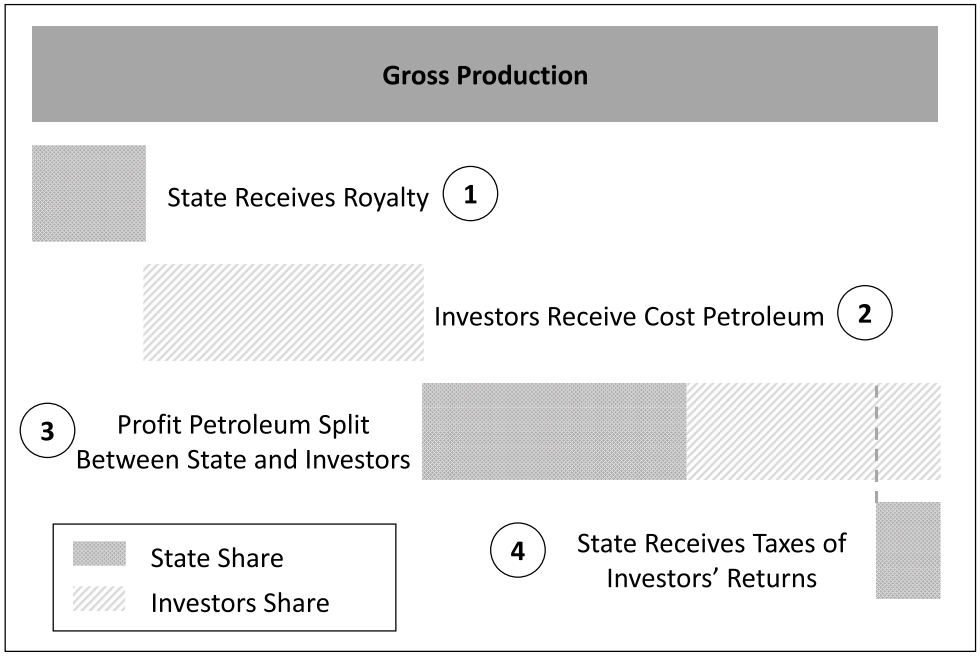

Fig. 1. Main elements of the PSC.

input parameters and decision variables discussed in the rest of this paper. When the state opts for awarding petroleum rights through bidding, it looks for maximizing the following objective function:

$$OF1 = \sum_{t=1}^{T} \frac{TGT[t]}{(1+i_s)^t} \tag{1}$$

where t refers to a time period, T is the project horizon, i_s is the state discount rate, and $TGT[t]$ refers to the total returns of the state (total government take) in period t composed of the royalty $\rho[t]$, the state profit petroleum $PP_s[t]$ and taxes $tax[t]$ at time period t as follows:

$$TGT[t] = \rho[t] + PP_s[t] + tax[t]$$

Companies interested in competing for petroleum rights have to set their bids after performing the necessary technical evaluations in a way that aims to achieve their required rate of return (RoR) given their reserve/cost/price estimations while maximizing (OF1). Their RoR corresponds to their discount rate for the particular project under consideration that naturally should incorporate all the foreseen underground and above-ground risks.

4. Modified PSC with renewable contribution (PSC-RC)

To explore the common drive of developing countries and OGCs to increase their investments in the renewable energy sector, we propose to introduce a new parameter to the PSC, RC_d, that defines the share of the company profit petroleum that the company is committing to re-invest in the renewable energy sector within the state. This share is still owned by the company. The state therefore is no longer only interested in maximizing its NPV from the oil and gas returns of the project, it also wants to maximize the commitments that the companies are making to re-investments in the renewable energy sector within the boundaries of the country.

Fig. 2 displays the dynamics of the PSC-RC: the state would like to set the "rules of the game" by defining the objective function that it aims to maximize along with the necessary constraints and the biddable items. The rules of the game are affected by several factors: the state should first *identify* the OGCs that it targets by understanding their interest in investing in the country, their estimated risk appetite and return requirements. This step includes carefully designing qualification requirements as part of the bidding process to guarantee that bidders possess the necessary experience and know-how to operate in the target country. The state also *defines* its own scenarios and projections for the oil and gas resources available in the area under tendering so that it can tailor the requirements to ensure enough economic attractiveness to the OGCs. Additionally, since the goal of the introduction of the RC_d item is to ensure that companies are committing to renewable energy investments, the state should *develop* its renewable energy strategy that *quantifies* renewable energy investment needs in the country. An OGC interested in acquiring petroleum rights will then "play the game" by first *defining* its estimations of the existing resources and the projections of the oil and gas prices. The OGC has to *define* its risk attitude and its expected returns on investments. These expectations *shape* the PSC bid that the OGC will set making sure that the bid *abides by* the rules of the game set by the state. The bid received and the rules of the game will *affect* the projected state oil and gas returns and the projected commitments to renewable energy within the state that the OGC is making. The state can then compare the commitments to renewable energy against the investment needs as determined by the renewable energy strategy in order to adjust the PSC-RC parameters for future bid rounds and to have a better understanding of the additional efforts required to fill-in the financing gap in renewable energy.

The state objective function should therefore be modified accordingly to become a multi-criteria objective function that maximizes the state oil and gas NPV first then the NPV of the commitments to renewable investments by the OGCs:

$$OF2 = \sum_{t=1}^{T} \frac{TGT[t] + \alpha.RC[t]}{(1+i_s)^t} \tag{2}$$

where $RC[t]$ corresponds to the renewable investments that the company is committing to make in time period t. This is equivalent to RC_d multiplied by the company share of the profit petroleum at time period t. The factor α reflects the relative importance to the state of commitments to renewable energy versus direct oil and gas returns. A value of $\alpha = 1$ indicates that a one dollar commitment to renewable energy investments is as important as a direct oil and gas return of one dollar. In this case, the state is indifferent to losing one dollar in direct oil and gas

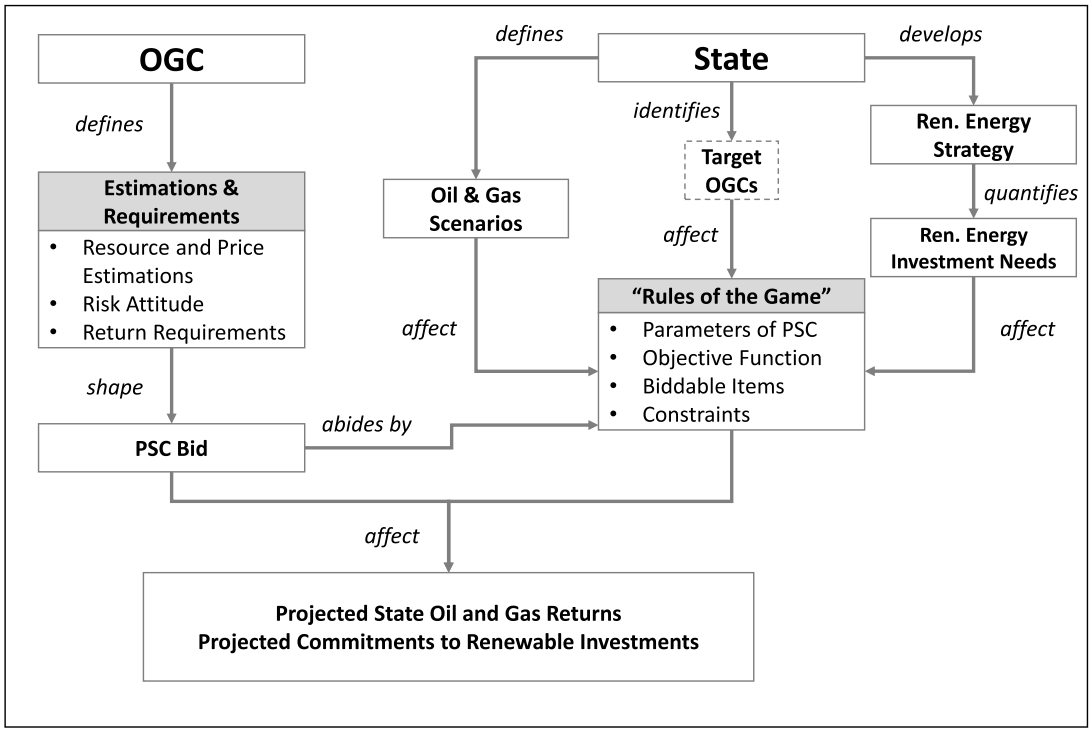

Fig. 2. Dynamics of the PSC-RC.

returns if the company uses this dollar as re-investments in renewable energy within the country. This is a full subsidy scheme that the state is unlikely to prefer (the situation becomes worse if α is greater than 1). On the other hand, setting α to 0 means that the state puts no value on commitments to renewable energy (while setting a negative value for α is even worse as it indicates that the state perceives commitments to renewable investments negatively). Therefore, reasonable values of α should be strictly between 0 and 1. In order to have the highest possible flexibility, the state can put no condition on the floor of RC_d. This means that OGCs can bid for RC_d as low as 0. This allows companies that are not yet interested in the renewable sector or are reluctant to commit to renewable investments in this particular state to bid a value of 0 for RC_d and still be able to compete for petroleum rights. A ceiling of RC_d can be set if the state estimates that an uncapped RC_d can result in commitments to renewable investments that exceed the needs of the state renewable energy sector.

4.1. Setting α

While α indicates the relative importance to the state of commitments to renewable energy versus direct oil and gas returns, setting it should also account for the economics of the project as perceived by the OGCs. The value of α can determine whether bidding for RC_d above 0 makes sense economically for the OGC or not.

At any time period t, the project returns ($ProjRet[t]$) are equal to the product of the production ($prod[t]$) and the price ($price[t]$). $ProjRet[t]$ can be divided into the following three components: the total government take ($TGT[t]$), the company petroleum revenues that are not re-invested in renewable energy ($PetrRev[t]$) and the commitments to renewable energy investments in time t ($RC[t]$). The state objective function (OF2) can accordingly be written as:

$$OF2b = \sum_{t=1}^{T} \frac{ProjRet[t] - PetrRev[t] - RC[t]}{(1+i_s)^t} + \alpha \cdot \frac{RC[t]}{(1+i_s)^t} \tag{2b}$$

By investing $RC[t]$, the company is expecting to make returns on these investments. Generally speaking, OGCs will be mostly interested in large scale renewable energy projects tailored for the generation of electricity. These projects are executed upon the signature of Power Purchase Agreements (PPAs) that provide annuity-like constant returns for a predefined renewable energy project duration T_r (HCB (2019)). Therefore, knowing the typical RoR of renewable energy projects within the state of consideration RoR_{ren}, the yearly annuity resulting from the investment of $RC[t]$ can be calculated as $Annuity = RC[t].(A/P, RoR_{ren}, T_r)$, where$(A/P, RoR_{ren}, T_r)$[2] is the capital recovery factor for an interest rate of RoR_{ren} and a period of T_r. Calculating the value of these annuities at period t requires to discount these cashflows at a certain interest rate. OGCs in transition to become energy companies set target RoRs for their renewable investments. Eni, for example, targets renewable projects generating RoRs between 8% and 12% (Pickl (2019)). Given a company discount rate for renewable projects i_{cRen}, the value of these annuity returns at time t is:

$$RCVal[t] = \frac{Annuity}{(A/P, i_{cRen}, T_r)}$$

Therefore, the total revenues to the company in time period t are $PetrRev[t] + RCVal[t]$. Accordingly, for a company to achieve its required oil and gas RoR (i_c), the NPV of its revenues should equal the NPV of the costs:

$$\sum_{t=1}^{T} \frac{PetrRev[t] + RCVal[t]}{(1+i_c)^t} = \sum_{t=1}^{T} \frac{costs[t]}{(1+i_c)^t} \tag{OGC-RoR}$$

The company would like to set its bid to maximize (OF2b) subject to achieving (OGC-RoR). Let us consider two potential bids for an OGC: $bid1$ with $RC_d > 0$ and $bid2$ with $RC_d = 0$. The corresponding state objective values for both bids are:

[2] $(A/P, RoR_{ren}, T_r) = \frac{1}{a_{T_r, RoR_{ren}}} = \frac{RoR_{ren}(1+RoR_{ren})^{T_r}}{(1+RoR_{ren})^{T_r}-1}$

$$\sum_{t=1}^{T}\frac{ProjRet[t]-PR_{c1}[t]-RC_1[t]}{(1+i_s)^t}+\alpha.\frac{RC_1[t]}{(1+i_s)^t} \quad \text{(bid1-Obj)}$$

$$\sum_{t=1}^{T}\frac{ProjRet[t]-PR_{c2}[t]}{(1+i_s)^t} \quad \text{(bid2-Obj)}$$

As α increases, bid1-Obj increases while bid2-Obj remains constant. For a threshold value of α_{th} high enough, bid1-Obj becomes higher than that bid2-Obj incentivizing the OGC to bid for $RC_d > 0$. In fact, at values of $\alpha \geq \alpha_{th}$, the OGC is incentivized to maximize the RC_d value, as the OGC would be better off investing money in renewable energy rather than receiving it in direct returns. A state can estimate the value of α_{th} by running simulations on its base resource projections and the profiles of the OGCs it targets as shown in the remaining sections of this document.

5. The Lebanese case

Lebanon awarded the first upstream petroleum rights in December 2017 (LPA (2017)). Additionally, the first PPA to purchase electricity generated from renewable energy sources was signed in February 2018 (Jabbour and Farhat (2018)).

5.1. The Lebanese PSC

Lebanon adopts a PSC with royalty and taxes. For natural gas, the royalty rate ρ_g is set to 4%, while for oil, ρ_o varies between 5% and 12% depending on the production rate (COM (2017)) and the Corporate Income Tax rate (*CIT*) is set to 20% (LP (2017)). The cost petroleum and profit petroleum are determined by bidding according to the following (COM (2017)):

- The cost petroleum ceiling CP_d is a biddable item with a ceiling of 65%. Costs can be indefinitely carried forward for cost recovery purposes. For the ease of readability, all biddable items have a *d* subscript to indicate that they are decision variables in a certain optimization model.
- The profit sharing between the state and the company is based on the R-factor. The Lebanese R-factor is computed every time period and is the ratio of the accumulated revenues of the companies less the accumulated operational expenditures to the accumulated capital expenditures until the previous period. Costs and revenues are simply added without discounting them. Fig. 3 shows the progression of the state share of profit petroleum as a function of the R-factor: when the R-factor is below 1, the state share of the total profit petroleum is A_d which is a biddable item with a floor of 30%. When the R-factor becomes above another biddable item Rb_d, the state share of the total profit petroleum becomes B_d which is another biddable item conditioned to be greater than A_d. When the R-factor is between 1 and Rb_d, the state share of the total profit petroleum grows linearly between A_d and B_d.

CIT is applicable on the company taxable amount composed of its share of the profit petroleum and the cost petroleum less the depreciation of capital expenditures (LP (2017)).

The state therefore receives three different streams of returns that constitute together the TGT: royalty, state share of profit petroleum and corporate income tax.

Lebanon awards petroleum rights only through licensing rounds (LP (2010)). A petroleum right is awarded to a consortium of at least three prequalified companies with at least one of them possessing offshore deep-water operatorship qualifications (COM (2017)). A published tender protocol defines the conditions of the bid round, the prequalification criteria for companies willing to participate in the bid round and the evaluation criteria (COM (2019)). Company bids are composed of technical and commercial components: the technical component has a weight of 20% and the commercial component a weight of 80%. The biddable items of the PSC constitute an integral part of the commercial component. The commercial bids are evaluated through nine published scenarios of three potential recoverable volumes and three different forecasted oil/gas price scenarios (Table 2). The tender protocol indicates that the commercial bids that maximize the average NPV of the

Table 2
Scenarios for evaluating the commercial component of upstream oil and gas bids in Lebanon (COM (2019)). Tcf refers to trillion cubic feet, mcf to thousand cubic feet and MMbbl to million barrels.

	Low Prices (4 $/mcf of Gas, 50 $/bbl of Liquids)	Base Prices (5.5 $/mcf of Gas, 65 $/bbl of Liquids)	High Prices (7 $/mcf of Gas, 80 $/bbl of Liquids)
Low Resources (2 Tcf of Gas, 14 MMbbl of Liquids)	OGSc1	OGSc2	OGSc3
Base Resources (5 Tcf of Gas, 35 MMbbl of Liquids)	OGSc4	OGSc5	OGSc6
High Resources (10 Tcf of Gas, 70 MMbbl of Liquids)	OGSc7	OGSc8	OGSc9

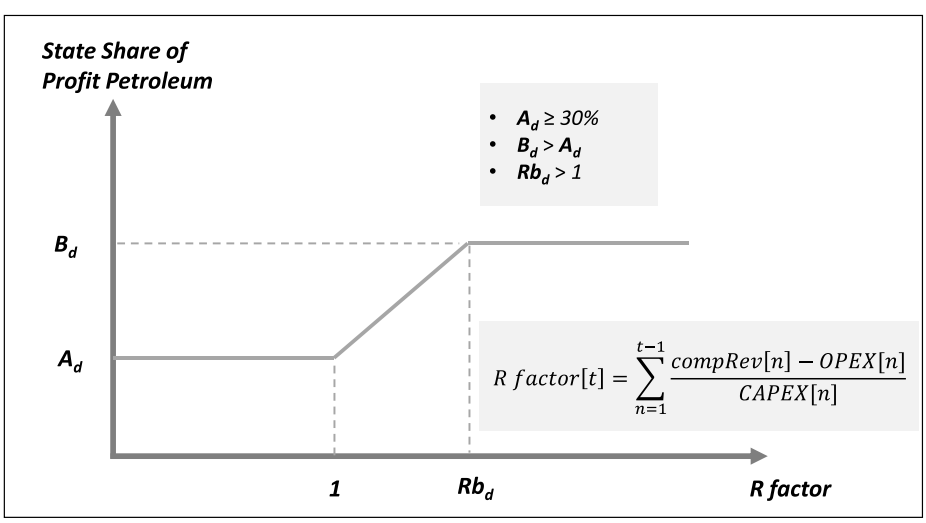

Fig. 3. State share of profit petroleum as a function of the R-factor.

state over the nine considered scenarios at the published state discount rate of 8% are given the maximum commercial score.

5.2. The renewable energy sector in Lebanon

Despite the Government's commitments to grow the renewable energy sector with announced goals of supplying 30% of the total national electricity demand from renewable sources by 2030 (MEW (2019)), progress so far has been limited. Only decentralized solar photovoltaic (PV) projects were able to grow in the local market whereas other renewable energy technologies have not made significant progress. This growth was mainly possible thanks to the National Energy Efficiency and Renewable Energy Action, a financing mechanism launched by the Lebanese Central Bank, which drove more than 60% of this relatively new market (Jabbour and Farhat (2018)).

In addition to the fiscal and economic crisis that Lebanon is currently suffering from, the implementation of larger scale renewable projects faces several specific barriers (IRENA (2020b)): The regulatory authority for the electricity sector is still not established and therefore the institutional framework for the sector is not complete. The electricity market is dominated by a single vertically structured state-owned entity that produces, transmits, and distributes electricity inducing ambiguity related to the details of the private generation licenses and the PPAs. The electricity tariff is subsidized, and the grid suffers from stability concerns. Other barriers include the limited access to data, the lack of local manufacturing of renewable energy components and the limited institutional capacity (Kinab and Elkhoury (2012)).

Despite these challenges, the Ministry of Energy and Water developed a process for awarding renewable energy production rights elaborated in Requests for Proposals (RFPs). These RFPs detail the qualification requirements for the applicants and the evaluation criteria of their bids. The qualification requirements include financial and technical elements to ensure that the applicant is capable of financing the project and of technically executing it with proven international experience in the field. An applicant can be a single company or a consortium of companies.

5.3. Applying the PSC-RC to Lebanon

In this section, we show how the dynamics of the PSC-RC highlighted in Fig. 2 can be applied to the case of Lebanon.

5.3.1. Defining oil and gas scenarios

The nine oil and gas scenarios put in-place to evaluate bids are used to project the reserve sizes and the future prices of hydrocarbons from the state point of view. Since these scenarios do not publicly disclose production or cost profiles, we develop our own estimates based on existing literature and petroleum assets in the East Mediterranean region that witnessed several important natural gas discoveries in the last decade. Table 3 shows the projected cost data for developments in Lebanon per thousand cubic feet (mcf) of Natural Gas: costs per mcf are expected to become smaller as the size of the field discovered becomes larger due to economies of scale. Capital Expenditures are assumed to be paid over a period of 4 years.

Petroleum rights in Lebanon are acquired through the signature of Exploration and Production Agreements (EPAs) with the state. EPAs extend over 30 years of which a maximum of 10 years is reserved to the exploration phase (LP (2010)). We consider that the production period extends over a period of 20 years. For the sake of the analysis, we assume that EPAs implementing the PSC-RC system are signed in 2021, and accordingly the production phase extends from 2031 to 2050. Since across the nine oil and gas scenarios, the fields under consideration are Natural Gas fields with small amounts of liquids, we develop the production profiles based on the typical behavior of gas fields as displayed in Fig. 4. Based on (Maddah et al. (2014)), and considering a plateau production phase of 10 years, the production profiles for the three reserve estimates (2 Tcf, 5 Tcf, 10 Tcf) considered in the nine scenarios are developed (Fig. 5).

Table 3
Costs of developing and producing the three considered reserve sizes (adapted from analogs in the east Mediterranean region (WoodMackenzie (2020))).

Recoverable Volume	CAPEX (USD/mcf)	OPEX (USD/mcf)
2 Tcf	1.1	0.60
5 Tcf	0.85	0.48
10 Tcf	0.60	0.40

5.3.2. Quantifying renewable energy investment needs

Since the state has only set renewable energy targets for 2030, and while across the nine oil and gas scenarios considered production starts in 2031 and extends till 2050, we develop three scenarios for the development of the renewable energy sector in Lebanon between 2031 and 2050. Solar PV technology constitutes 80% of the total feasible potential for renewable energy technologies in Lebanon (Al Assad (2016)). Additionally, given the Mediterranean sunny weather that the country enjoys, solar PV turns out to be the cheapest renewable energy technology for Lebanon (Al Assad (2016)). Therefore, across the three proposed scenarios, centralized solar PV is the technology of choice for the growth in the renewable energy sector. Additional estimations and assumptions that apply to all renewable energy scenarios are presented in Appendix B.

Scenario One (*RSc*1) - Green Revolution:*RSc*1 assumes that the preliminary 2030 targets estimated to be around 5 GW (IRENA (2019b)) are achieved, the renewable energy market has matured, and the Government appreciates the full resulting benefits. Additionally, the major sectoral reforms have been achieved. Therefore, aggressive renewable energy targets are set for 2050 based on the assumption that the market can replicate its behavior between 2020 and 2030. This means that the market is expected to continue adding 5 GW of renewable energy capacity every 10 years between 2031 and 2050 and accordingly, the 2050 targets would result under this scenario in 10 GW of added capacity.

Scenario Two (*RSc*2) - Sustainable Diversification:*RSc*2 suggests that the 2030 targets are successfully reached, and the Government is still sustainably investing in all its energy resources. However, the discoveries of indigenous Natural Gas resources incentivize the development of a local gas market in the electricity sector. Therefore, the state plans to maintain a 30% renewable energy share in the power mix while combined-cycle gas turbines plants that run on the discovered indigenous Natural Gas provide the remaining capacity. Therefore, the additional capacity of renewable energy required for 2050 under this scenario is estimated to be around 4.5 GW.

Scenario Three (*RSc*3) - Back on Track:*RSc*3 considers that only half of the ambitious renewable energy targets for 2030 are reached due to challenges such as limited financing opportunities, contracting economy and insufficient reforms. Still, the Government supports the renewable

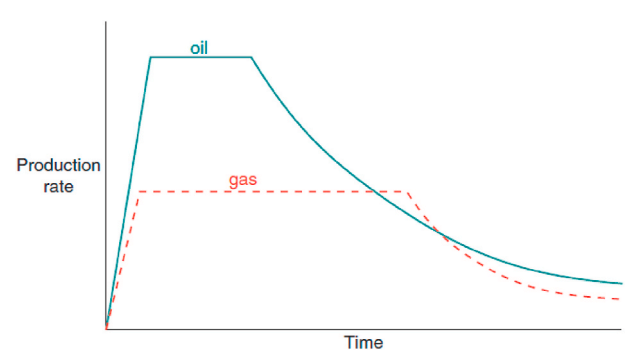

Fig. 4. Typical production profiles for gas fields and oil fields (Jahn et al. (2008)).

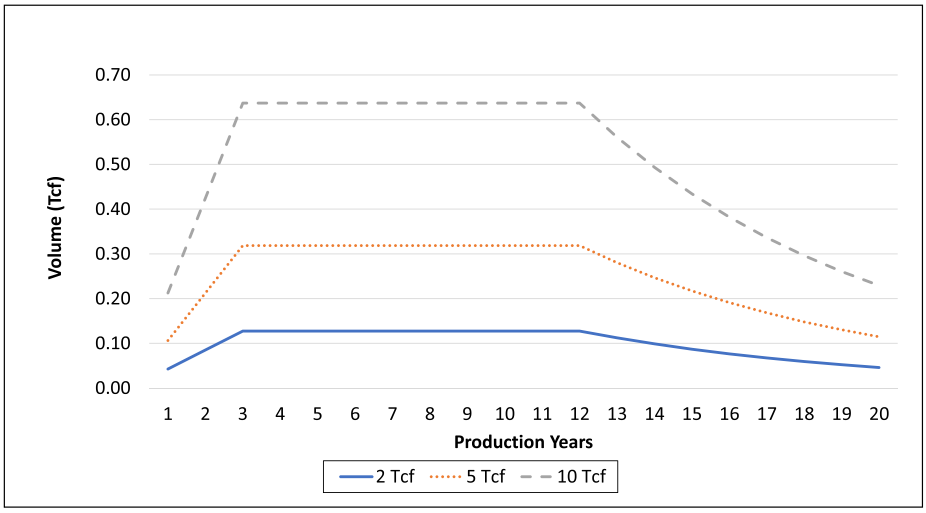

Fig. 5. Production profiles of the three considered reserve sizes.

sector and tries to provide an enabling environment for its development. Accordingly, the Government believes that the remaining 2.5 GW of renewable energy capacity needed to reach the 2030 targets can be achieved by 2040, and that an additional 5 GW of renewable capacity can be implemented by 2050 assuming some reforms and improvements will be made under stable economic and political conditions. Consequently, the 2050 targets would result under this scenario in 7.5 GW of added capacity.

Table 4 summarizes the capacity addition by scenario. The required financing needs are the product of the corresponding yearly capacity addition and the yearly unit cost. Unit costs for solar PV are dropping with time as the technology is maturing. Fig. 6 shows the yearly unit costs for Solar PV based on the International Renewable Energy Agency (IRENA) estimates for years 2018, 2030, and 2050 (IRENA (2019a)). Accordingly, the yearly investment requirements per scenario from 2031 to 2050 can be estimated (Fig. 7). Additionally, it is assumed that subject to policy reforms and to further derisking of the renewable energy sector in Lebanon, the average renewable project RoR in Lebanon over the long-term should be similar to that of typical projects in the region at 5% (Krupa et al. (2019)).

5.3.3. *Calibrating α and setting ceiling on RC_d*

In order to complete the definition of the rules of the game as per Fig. 2, the characteristics of the target OGCs that the state is interested in attracting should be defined: We consider that OGCs interested to invest in the upstream petroleum sector in Lebanon require petroleum RoRs of 15%, a typical RoR estimated based on RoRs of upstream petroleum projects in the Eastern Mediterranean region (WoodMackenzie (2020)), while they expect a 10% RoR on their renewable energy investments (Eni, one of three companies currently holding petroleum rights in Lebanon and one of the most active companies in the East Mediterranean region requires renewable energy investment RoRs of 8%–12% (Pickl (2019))). The state is willing to accept these RoR expectations especially for renewable energy given the current market risks in Lebanon and in return for early commitments from OGCs to the renewable energy sector. These commitments will contribute to further derisking the sector and to improving its future competitiveness.

Table 4
Capacity of newly added renewable energy projects under each scenario.

Scenario	Added Capacity		
	From 2031 to 2040	From 2041 to 2050	Total
*RSc*1	500 MW per annum	500 MW per annum	10,000 MW
*RSc*2	225 MW per annum	225 MW per annum	4,500 MW
*RSc*3	250 MW per annum	500 MW per annum	7,500 MW

Additionally, the state requires that applicants interested in signing PSC-RC contracts with Lebanon must possess both the qualification requirements for the upstream oil and gas operations and the renewable energy technology they plan to use. An individual company may or may not possess all the qualification requirements, yet, the applicant, which can be composed of a consortium of companies, must possess them all to qualify for the award of the PSC-RC rights. We note here that two of the three companies currently holding petroleum rights in Lebanon (Total and Eni) possess the necessary upstream petroleum and renewable energy expertise.

We propose to introduce the RC_d biddable item to the existing Lebanese PSC with minimal changes. Therefore, the objective function of the state is modified from (OF1) to (OF2) where the already in-place four biddable items (A_d, B_d, Rb_d, CP_d) along with their constraints are maintained. The complete optimization model is presented in Appendix C. What requires special care is two-folds: calibrating α for the specific case of Lebanon and setting the right constraints on the introduced RC_d biddable item.

The state uses its base oil and gas scenario (base resources, base prices) to estimate α. The experiment goes as follows: for values of α ranging from 0 to 1 with increment of 0.01, the optimization model defined in Appendix C is run using IBM CPLEX Solver. The output of the optimization model is the five biddable items (A_d, B_d, Rb_d, CP_d, RC_d). In this experiment, RC_d is allowed to vary over the whole possible range of 0–1. When α is 0 or very small, the resulting RC_d is 0 as there is no or very little contribution from the commitments to renewable energy investments to the objective function. When α becomes large enough, the optimal bid will have an RC_d above 0. It turns out that this threshold value α_{th} is 0.36. Therefore, we set α to 0.36 in the objective function as the aim is to have α large enough to promote renewable investments but not too large to avoid unnecessary additional returns to the companies.

As for the RC_d biddable item, the floor is kept as low as 0 to accommodate companies that are not interested in investing in the renewable energy sector in Lebanon. The ceiling depends on the renewable energy sector investment needs in Lebanon. We run a second experiment to set a ceiling on the RC_d item by comparing the NPV of renewable energy commitments under different ceiling values of RC_d against the NPV of the projected renewable energy investment needs for the three renewable energy scenarios. Fig. 8 shows these NPVs in 2030 when RC_d is varied between 10% and 40%. These values are derived for the base case oil and gas scenario and for the characteristics of the target OGCs as earlier defined. If the state wants to satisfy most of its

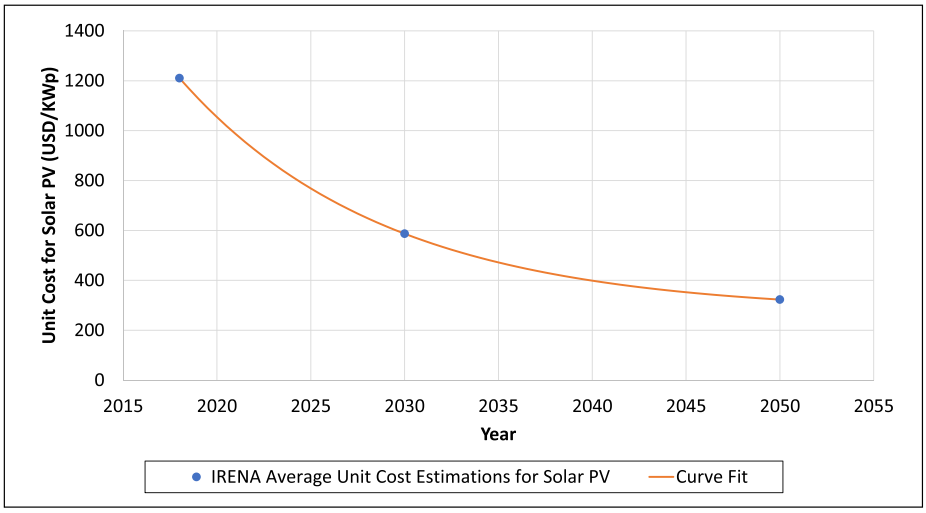

Fig. 6. Yearly unit costs for installing solar PV.

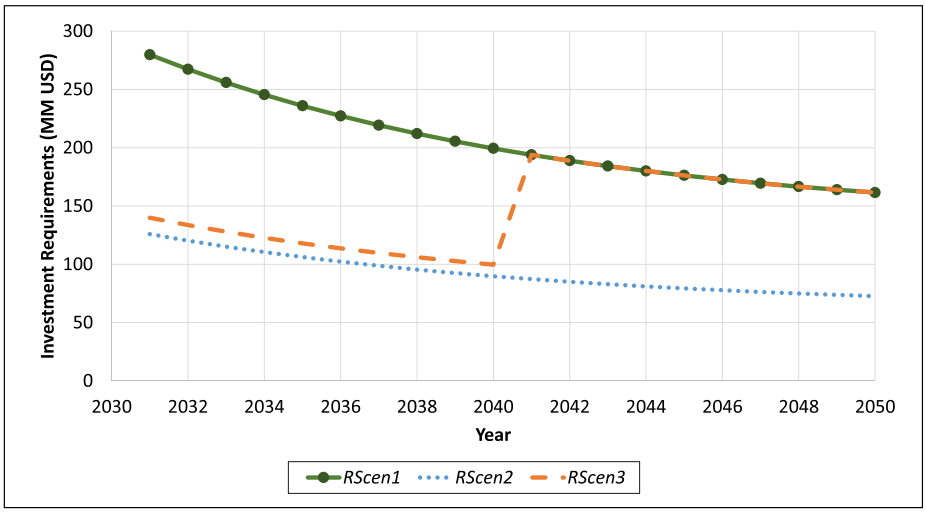

Fig. 7. Investment requirements under each renewable energy scenario.

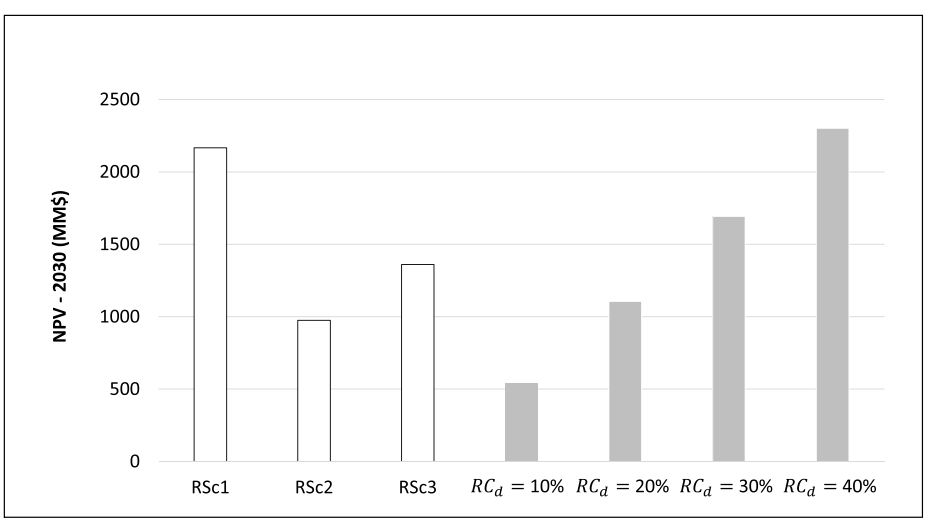

Fig. 8. NPV (2030) of renewable energy investment needs for the three renewable energy scenarios and renewable energy commitments for different values of RC_d under the base case oil and gas scenario.

investment needs regardless of the renewable energy scenario, then the RC_d ceiling should range between 20% and 40%. However, if the state wants to use the investment commitments from the oil and gas sector to catalyze the renewable energy sector and to provide firm commitments that can later be complemented by competing investments from other sources, then an RC_d ceiling of 10% should serve the purpose. Already for $RC_d = 10\%$, commitments to renewable energy investments satisfy a considerable share of the renewable energy investment needs ranging between 25% and 55% depending on the renewable energy scenario for the base case oil and gas scenario. Therefore, we set 10% as the ceiling on RC_d.

The objective function of the Lebanese PSC-RC model along with the constraints on the biddable items are therefore as follows (complete model described in Appendix C):

$$OFLeb = \sum_{t=1}^{T} \frac{TGT[t] + 0.36.RC[t]}{(1+i_s)^t} \quad \text{(OFLeb)}$$

$$\max\ (OFLeb)$$

$$s.t.:$$

$$A_d \geq 30\%$$

$$B_d > A_d$$

$$Rb_d > 1$$

$$0 \leq CP_d \leq 65\%$$

$$0 \leq RC_d \leq 10\%$$

The analysis is completed for the nine oil and gas scenarios (OGSc1 to OGSc9) and the commitments to renewable energy investments are analyzed for the three renewable energy scenarios (RSc1 to RSc3).

6. Results and discussion

In this section, we show how the proposed Lebanese PSC-RC model behaves when OGCs are responding to it. We analyze the results for three different OGCs with different risk appetites for petroleum projects and renewable energy projects. *OGC*1 fits perfectly with the OGC model perceived by the state, while *OGC*2 is a company that is only interested in large discoveries. *OGC*2 is still cautious with renewable energy and open to consider only renewable energy projects with very high returns. Therefore, it requires higher RoRs on its investments. Finally, *OGC*3 is a smaller company satisfied with lower RoRs and with smaller discoveries. OGC3 is forming a consortium with a specialized renewable energy company to be able to deliver on both the upstream petroleum and the renewable energy projects. We assume that the OGCs set their bids based on their most conservative projections of the existing reserves. Accordingly, *OGC*1 bids according to reserve estimates of 5 Tcf, *OGC*2 to reserve estimates of 10 Tcf and *OGC*3 to reserve estimates of 2 Tcf (Table 5). Each company will proceed to developing the field only if it discovers reserves at least matching its expectations. We also assume that all companies use base price forecasts when setting their bids.

The companies would like to maximize the state objective function (OFLeb) while abiding by the constraints on the biddable items and achieving their RoRs. They also want to maximize their upside in case of larger discovery size than expected. The resulting optimal bids for each company as obtained after running the optimization model on IBM CPLEX Solver are shown in Table 6. Several interesting observations can be made: for the three OGCs, A_d is set to the minimum possible value of 30% and CP_d to the maximum possible value of 65%. This is intuitively justified by the fact that for all three OGCs their required i_c is above the state discount rate. Therefore, earlier cash is worth more to the companies than it is worth to the state. Maximizing early cash to the OGCs is guaranteed by setting A_d and CP_d to the minimum and maximum possible values respectively. This goes in line with the findings of Maddah et al. (2014). For *OGC*1 and *OGC*3, RC_d is set to the maximum possible value of 10%. This is justified by the favorable value of α in the objective function that promotes commitments to renewable energy for *OGC*1 and *OGC*3. On the other hand, the high RoR requirements for *OGC*2 makes an α value of 0.36 unattractive for it to commit to renewable energy investments within Lebanon. In fact, if Lebanon was interested in attracting commitments to renewable investments from *OGC*2 and if α was calibrated accordingly, then α_{th2} would be as high as 0.64. This falls out of the interest of the state and therefore, the optimal bid for *OGC*2 has a 0 value for RC_d. However, *OGC*2 is still able to compete for petroleum rights in Lebanon. As for *OGC*1 and *OGC*3, an α value of 0.36 is greater than or equal to their respective α_{th} (Table 7).

Figs. 9 and 10 show the percentage share of the renewable investment needs that are provided from the renewable energy commitments for *OGC*1 and *OGC*3 respectively. These shares are displayed for all possible combinations of renewable energy and oil and gas scenarios. For *OGC*1, when the reserve size is 2 Tcf, the field is not developed and therefore no commitments to renewable contributions are made. Otherwise, these commitments increase with increasing reserve sizes and prices. The same pattern is observed for *OGC*3. For a small reserve size of 2 Tcf, commitments to renewable energy range between 6% and 22% of the investment needs of the different renewable scenarios. This share is already considerable and can induce positive market effects on the attractiveness of renewable energy investments from other competing sources. When 5 Tcf are discovered, the commitments to investments in renewable energy become sizable and can constitute up to 32%, 71% and 51% of the investment needs of RSc1, RSc2 and RSc3 respectively. At this stage the oil and gas sector becomes a main source of funding to the renewable energy sector in Lebanon while leaving considerable room for other sources of funding. When 10 Tcf are discovered, the oil and gas sector then becomes the dominant source of funding to the renewable energy sector. In fact, funding available can exceed needs when prices are at the base or high levels for RSc2. To deal with such cases, the PSC-RC system can include terms that allow the redistribution of the excessive investment commitments in cash to the OGC and the state according to the profit petroleum split or to let the OGC cash its excess commitments to renewable energy. The state can avoid such scenarios by setting a lower ceiling on RC_d at the expense of lowering commitments to renewable energy investments in other scenarios.

6.1. Analyzing the effects of RC_d on TGT

The objective function (OFLeb) of the Lebanese PSC-RC shows that the state is collecting value from two sources: the *TGT* representing the state direct oil and gas returns, and the renewable contributions (*RC*) that the companies are committing to. OGCs can design their bids with

Table 5
Different profiles of OGCs.

OGC	i_c	i_{cRen}	Reserve Estimate Used to Set Bid
*OGC*1	15%	10%	5 Tcf
*OGC*2	20%	15%	10 Tcf
*OGC*3	11%	7%	2 Tcf

Table 6
Optimal bids for the three OGCs.

OGC	A_d	B_d	R_b	CP_d	RC_d
*OGC*1	30%	68.2%	3.51	65%	10%
*OGC*2	30%	70.1%	4.71	65%	0%
*OGC*3	30%	79.3%	2.52	65%	10%

Table 7
α_{th} correspondent to the profile of the different OGCs.

	*OGC*1	*OGC*2	*OGC*3
α_{th}	0.36	0.64	0.15

different offerings to the state on both of these sources. Intuitively, when an OGC commits to renewable contributions, it automatically can generate more oil and gas returns to itself (and therefore less to the state) while achieving the same objective value to the state. In order to illustrate this trade-off, we compare the bids of *OGC*1 and *OGC*3 against optimal bids that *OGC*1 and *OGC*3 would have made before the introduction of the RC_d item. These bids can be obtained by running the optimization model on the input parameters for *OGC*1 and *OGC*3 while setting RC_d to 0. According to Fig. 11, the introduction of the RC_d biddable item results in bids that reduce the *TGT* of the state by median values of 2.98% and 0.84% for *OGC*1 and *OGC*3 respectively. The lower drop in *TGT* for *OGC*3 is justified by its low required return on investment for its renewable energy projects ($i_{cRen} = 7\%$) that is below the corresponding value for *OGC*1 of $i_{cRen} = 10\%$. This basically means that *OGC*3 is content with lower direct oil and gas returns than the ones required by *OGC*1 when moving to a bid of $RC_d > 0$. This results in lower reduction in the state *TGT* for *OGC*3. The wider spread of values for *OGC*3 is due to the larger number of scenarios for which fields are developed (nine scenarios compared to six scenarios for *OGC*1).

However, these reductions in *TGT* are compensated by an increase in the total money retained in the country composed of both the *TGT* and the *RC*. Fig. 12 shows that for each dollar drop in *TGT*, the total money retained within the country increases by median values of 1.62 and 6.11 dollars for *OGC*1 and *OGC*3 respectively. The introduction of RC_d can therefore constitute a driving force for increasing the retention of value within the country from the produced petroleum resources, a main concern for developing countries contracting international companies that tend to transfer their shares of returns outside the host countries. This can have several implications on the value addition from the petroleum sector not only through the support it provides to the renewable energy sector but also through its other indirect benefits such as the increase in employment due to the local renewable energy investments made and the contribution to the economic activities in Lebanon. This offers an opportunity for the capital intensive upstream petroleum sector not characterized by its job creation capabilities to promote the renewable energy sector that has the potential to create considerable

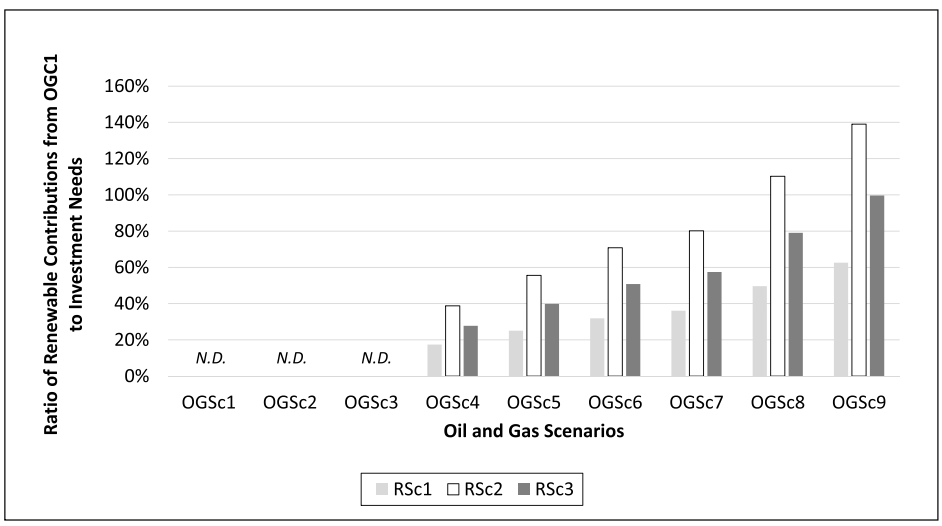

Fig. 9. Ratio of renewable energy contributions from *OGC*1 to the investment needs for the various scenarios (NPV 2030 numbers). *N.D.* refers to field not developed.

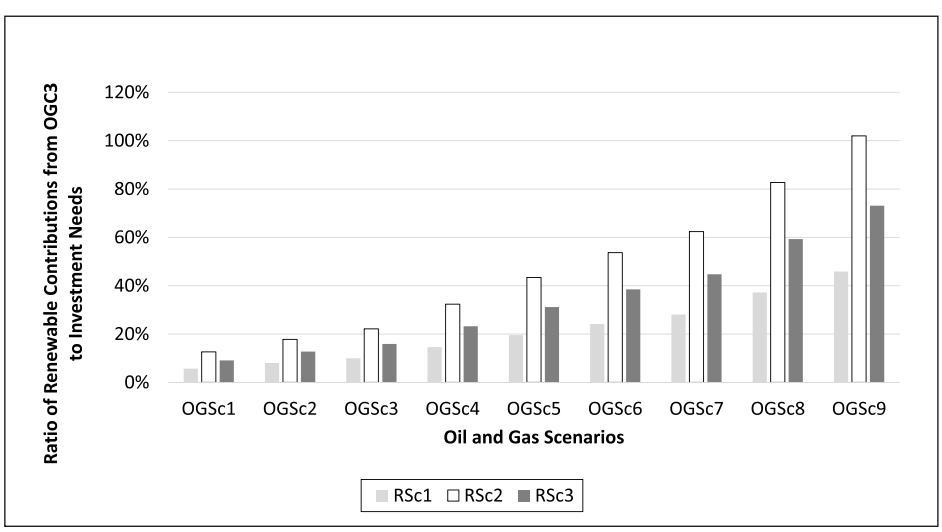

Fig. 10. Ratio of renewable energy contributions from *OGC*3 to the investment needs for the various scenarios (NPV 2030 numbers).

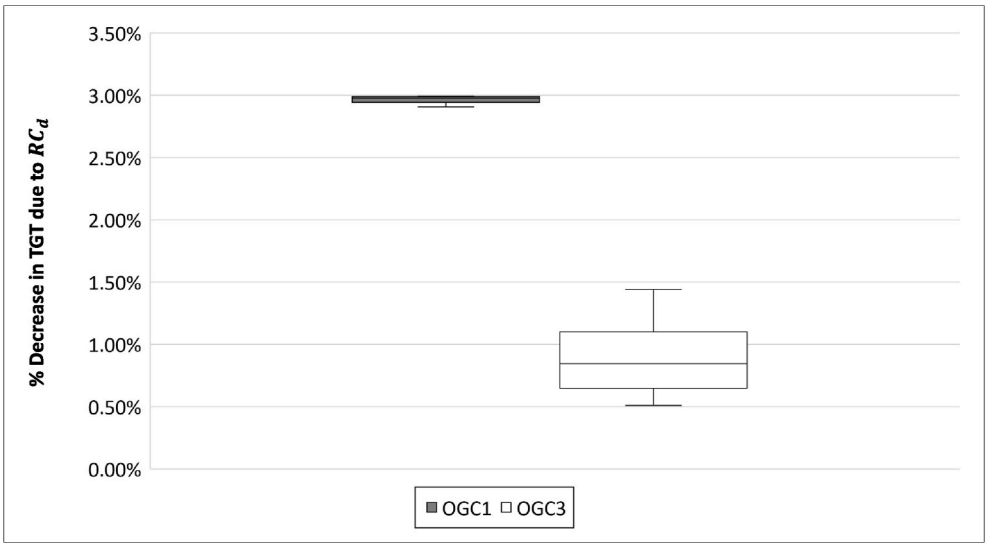

Fig. 11. % Decrease in state *TGT* due to the introduction of the RC_d item across oil and gas scenarios (NPV 2030 numbers).

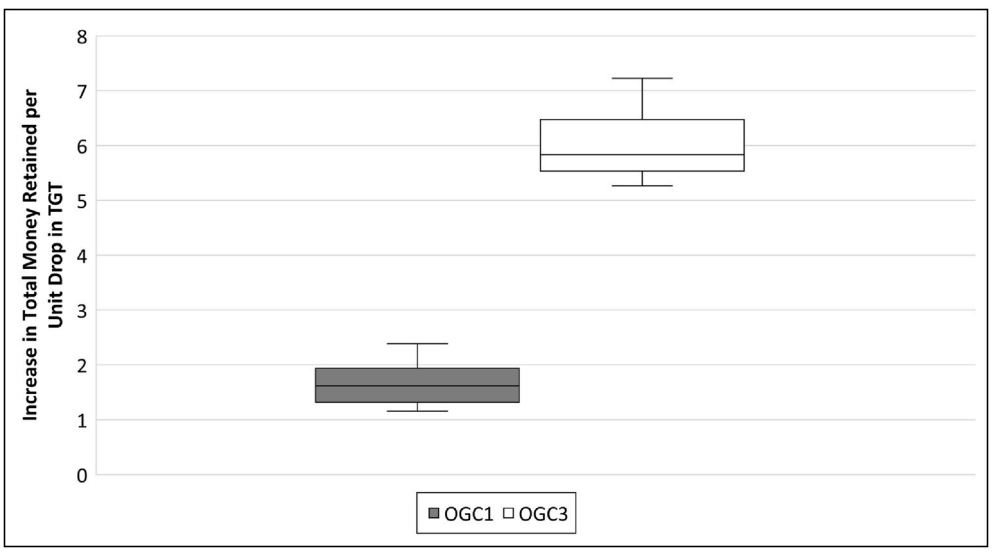

Fig. 12. Increase in total money retained within the country Per unit drop in *TGT* across oil and gas scenarios (NPV 2030 numbers).

jobs in the market (UNDP (2019)).

6.2. Direct environmental impacts

The renewable contributions of *OGC*1 and *OGC*3 result in increasing the installed PV capacity in the country replacing conventional power plants. The electricity policy for Lebanon stipulates that future power generation will mostly be sourced by Combined Cycle Gas Turbines (CCGT) and renewable energy sources (MEW (2019)). To assess the direct environmental impacts of the PSC-RC, we measure the conventional CCGT-generated electricity that will be replaced by the added PV capacity through the renewable contributions of *OGC*1 and *OGC*3 along with the associated CO2eq savings. We assume that the capacity factor of the PV projects is the average number for Lebanon of 19.83% (Al Assad (2016)) and that the emission factor for CCGT is 0.346 tonnes of CO2eq/MWh (Lazard (2020)). By 2040, the yearly CO2eq savings have median values of 1.19 and 0.72 million tonnes CO2eq/year for *OGC*1 and *OGC*3 respectively (Fig. 13). By 2050, these median savings increase to 2.13 and 1.14 million tonnes CO2eq/year respectively. The maximum savings can reach 2.15 million tonnes of CO2eq/year by 2040 and 3.72 million tonnes of CO2eq/year by 2050. To put these savings into perspective, the latest published emissions data for Lebanon indicate that the total CO2eq emissions in 2015 was 27.1 million tonnes (MOE (2019)). Therefore, the renewable contributions induce a reduction of up to 7.9% and 13.7% of the 2015 total national yearly emissions by 2040 and 2050 respectively.

7. Conclusion and policy implications

Climate change is a serious threat to the future of humanity. Developing countries endowed with oil and gas resources and struggling to achieve economic development should also push for the development of their renewable energy sectors. Several regulatory, commercial, technical and institutional barriers face the upscale of renewables in these countries. On the other hand, many oil and gas companies are approaching the energy transition with spirits of opening their activities to the wider energy market by considerably investing in renewable energy while enhancing their competitiveness in their core upstream oil and gas business. The drivers for this shift in priorities are mainly economic associated to the increased profitability and predictability of

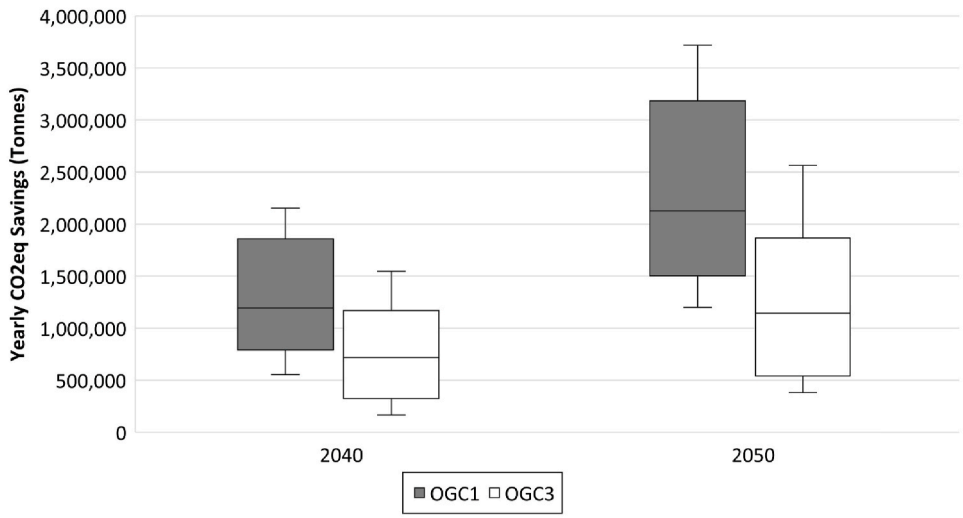

Fig. 13. CO2eq yearly savings due to *OGC*1 and *OGC*2 renewable contributions in 2040 and 2050 across oil and gas scenarios.

returns of renewable energy technologies when compared to upstream investments holding increased market risks. The reputational risk comes in the second place as oil and gas companies cannot shy away from the effects of climate change and are expected to play a constructive role in this regards.

To the best of our knowledge, this paper proposes for the first time an upstream oil and gas contract that includes renewable energy elements within it. We illustrate how the Production Sharing Contract (PSC), the most common contracting form for developing countries with oil and gas companies, can be modified to incorporate renewable energy elements through the introduction of the Renewable Contribution RC_d parameter. The proposed PSC-RC contract allows the state to bundle interesting investment packages in the upstream petroleum and the renewable energy sectors that can attract capable companies possessing historical experience in dealing with typical investment barriers faced in the context of developing economies and able to deliver on both fronts. The PSC-RC contract seems fully aligned with the strategies of oil and gas companies in the transition to become energy companies. It allows them to run their parallel businesses in oil and gas and renewable energy enabling the reduction of oil and gas price risks at project level rather than at company level. Additionally, the PSC-RC contract enables a smooth expansion of the activities of oil and gas companies operating in developing countries to the wider energy sector in these countries increasing the scale of the national involvement of the oil and gas companies and enhancing the efficiency of their operations. We develop the complete optimization model for the application of the PSC-RC model on the Lebanese case.

Beside implementing the PSC-RC, the presented optimization model implements for the first time the details of the Lebanese PSC contract including variable state share of profit petroleum and the indefinite loss carry-forward among other elements through an Integer Linear Program.

The application of the modified PSC-RC model on the Lebanese case shows that for a small Renewable Contribution parameter of 10% of the company profit petroleum, the renewable energy sector in Lebanon is provided with considerable funding sources sizable enough to energize the sector and promote competition. The ceiling on the RC_d parameter can even be lower if multiple license areas are awarded in parallel with higher total oil and gas resource expectations allowing for a gradual transition from the PSC to the PSC-RC. This illustrates that small commitments from the company side can have strong implications on the renewable energy sector of the host country. Although the introduction of the RC_d parameter results in the reduction of the state direct oil and gas share, the reduction is very limited and is outweighed by the increased retention of value from the oil and gas project within the state and the considerable savings in CO2eq emissions. Other indirect effects that can result from these renewable energy commitments are also important to highlight. The presence of large energy companies on-board supporting the implementation of the renewable energy strategy of the state builds local expertise on one hand, and creates jobs and business opportunities that contribute to increasing local content, a goal commonly on the government list for upstream petroleum projects.

One main fear from the company side is whether the state can guarantee that the company is allowed to spend its commitments to renewable energy timely. This issue is exacerbated when renewable energy projects are awarded based on tendering as is the case in Lebanon. The state can in practice introduce soft changes to the terms of the Request for Proposal Package by requiring guaranteed financing as early as bid stage. Having their financing readily available, oil and gas companies will then be in favorable position for such projects and will be highly competitive.

Dealing with over commitments to renewable energy investments in the proposed PSC-RC model is an issue that requires detailed analysis. However, one way is to consider that these over-commitments are regular petroleum returns that should be distributed between the state and the company based on the regular profit sharing mechanism of the PSC. Other potential solutions are left for future research. Similarly, this paper assumes that the renewable energy investments of the oil and gas companies are limited to renewable energy production, in particular, centralized solar PV in the case of Lebanon. Several other investment schemes can be studied such as the investment in other renewable energy technologies or the establishment of green banks funded by the oil and gas companies to provide financing for smaller scale renewable energy projects at fixed interest rates. The analysis of these alternative investment techniques is also left for future work.

This paper uses the rate of return requirements from the oil and gas companies as a proxy for their risk appetite and combines that with their projections for existing resource to determine their interest in investing in Lebanon. Alternative more complex company models that do not treat investment decisions as binary yes or no decisions but rather dynamic decisions that take into consideration the way the PSC-RC contract is designed are also interesting to address in the future.

CRediT authorship contribution statement

Majd Olleik: Conceptualization, Methodology, Software, Formal

analysis, Writing – original draft. **Hans Auer:** Conceptualization, Supervision, Project administration. **Rawad Nasr:** Data curation, Investigation, Writing – original draft.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Majd Olleik provides consulting services to the Lebanese Petroleum Administration.

Rawad Nasr provides consulting services to the Lebanese Center for Energy Conservation.

The views expressed in this paper are those of the authors solely.

Appendix A. Renewable Energy Status and Plans for European Majors

After Statoil rebranded itself as Equinor in 2018 to indicate that it is moving from being an oil company to a company focusing on equilibrium in its energy operations, it is now building the world's largest floating offshore wind farm and has high hopes to lead the way in this sector leveraging its experience in offshore oil and gas operations (Equinor (2020b)). BP, Shell and Total declared in 2020 that they aim to run a net-zero emission energy business by 2050 (BP (2020b); Shell (2020b); Total (2020c)). BP, Shell, Total and Eni are all rebranding themselves as energy companies (BP (2020d); Shell (2020c); Total (2020a); Eni (2020c)). BP aims to lead the way in the renewable energy sector by planning to develop 50 GW of net renewable generation capacity by 2030 and to increase its yearly renewable investments to 5 Billion USD (BP (2020c)). Total targets the installation and operation of 25 GW of power generation capacity from renewable sources, mainly wind and solar, by 2025 (Total (2020b)). Total CEO announced that by 2050 the ambition is for Total portfolio to be composed of 40% of renewable energy sources to position Total among the top five producers of renewable energy (Benezet (2020)). Eni is "changing direction to become a leader in the production and sale of decarbonized products" (Eni (2020c)). To achieve that the company is creating two new business groups: Natural Resources for the upstream oil and gas focus area, and Energy Evolution focusing on the transition that the company is committing to undertake (Eni (2020a)). Eni targets the installation of 15 GW of renewable electricity generation by 2030 and more than 55 GW by 2050 (Eni (2020b)).

Appendix B. Renewable Energy-related Parameters and Estimations

Table B.8 provides the input parameters used across the various renewable energy scenarios. Additionally, the following assumptions are made:

- Priority of generation and dispatch favors renewable energy.
- Electricity demand and supply are equal in 2030.
- The capacity cap for onshore wind and hydro is reached in 2030.
- The added capacity of renewable energy beyond 2030 will largely rely on centralized solar PV.
- Enabling technologies such as storage, interconnections, spinning reserves, and demand side response are implemented to allow high penetration levels of renewable energy.
- Adequate grid impact analysis and capacity expansion planning are performed.
- Grid connection costs and O&M fees are not considered to be part of the financing requirements.
- Financing commitment is required upon the start of the projects.

Table B.8
Renewable energy parameters.

Parameter	Value	Source
Yearly Growth of Electricity Demand	2.76%	MEW (2019)
Transmission and Distribution Losses	8%	MEW (2019)
Average Capacity Factor for Solar PV	19.83%	Al Assad (2016)
Average Commercial Life of Solar PV	20 Years	NREL (2017)

Appendix C. Complete Optimization Model of the Lebanese PSC-RC

This appendix provides the complete optimization model for the Lebanese PSC-RC.

The objective function is the following:

$$\max\left(\sum_{t=1}^{T}\frac{TGT[t]+\alpha\cdot RC[t]}{(1+i_s)^t}\right) \tag{C.1}$$

In what follows, we present the input manipulations and the constraints of the model. The total government take at period t is composed of the royalty $\rho[t]$, the state share of the profit petroleum $PP_s[t]$ and the taxes $tax[t]$:

$$\forall t, TGT[t]=\rho[t]+PP_s[t]+tax[t] \tag{C.2}$$

The royalty at period t corresponds to the natural gas royalty and the oil royalty at period t. For natural gas and oil, the respective royalty corresponds to the royalty rate ρ_g or ρ_o multiplied by the revenues that each source is generating at period t. The revenues are the product of the produced volumes $Prod_g[t]$ and $Prod_o[t]$ by the prices $Price_g[t]$ and $Price_o[t]$.

$$\forall t, \rho[t]=\rho_g\cdot Prod_g[t]\cdot Price_g[t]+\rho_o\cdot Prod_o[t]\cdot Price_o[t] \tag{C.3}$$

C.4-C.8 impose the limits on the five biddable items A_d, B_d, Rb_d, CP_d and RC_d respectively.

$$A_d \geq 30\% \tag{C.4}$$

$$B_d > A_d \tag{C.5}$$

$$Rb_d > 1 \tag{C.6}$$

$$0 \leq CP_d \leq 65\% \tag{C.7}$$

$$0 \leq RC_d \leq 10\% \tag{C.8}$$

At every period, the disposable petroleum corresponds to the post-royalty revenues:

$$\forall t, DP[t] = \left(1-\rho_g\right)\cdot Prod_g[t]\cdot Price_g[t] + (1-\rho_o)\cdot Prod_o[t]\cdot Price_o[t] \tag{C.9}$$

The cost petroleum is the share of the disposable petroleum delivered to the OGC to recover its costs. at each period t, it is the minimum between the outstanding balance of unrecovered costs and the maximum cost recovery possible in this period. The latter corresponds to $CP_d\cdot DP[t]$:

$$\forall t, CP[t] = min\left(\sum_{n=1}^{t-1} CAPEX[n] + OPEX[n] - CP[n] + CAPEX[t] + OPEX[t], CP_d \cdot DP[t]\right) \tag{C.10}$$

We note that this constraint is difficult to linearize. Additionally, the decision variable CP_d causes non-linearity in many other constraints. Therefore, similar to Maddah et al. (2014), instead of solving a non-linear optimization program, we can solve several linear optimization programs by considering CP_d as an input parameter rather than a decision variable and by varying its value over the desired range. Since $0 \leq CP_d \leq 65\%$, we consider CP_d as an input parameter and we solve the program while varying it between 0 and 65% one percentage point at a time (and accordingly considering 66 different values for CP_d). We later can choose the CP_d (along with the other decision variables) for which the objective function is maximized. When CP_d is treated as an input, C.10 is no longer a constraint as it becomes fully dependent on the input parameters. For the discussion of the remaining constraints, we treat CP_d as an input parameter.

The profit petroleum at period t corresponds to $DP[t] - CP[t]$. The state profit petroleum $PP_s[t]$ is the profit petroleum at period t multiplied by the state profit petroleum share at period t, $PS[t]$. The company profit petroleum $PP_c[t]$ is the remaining amount.

$$\forall t, PP_s[t] = (DP[t] - CP[t])\cdot PS[t] \tag{C.11}$$

$$\forall t, PP_c[t] = (DP[t] - CP[t])\cdot(1 - PS[t]) \tag{C.12}$$

$PS[t]$ varies between A_d and B_d according to the R-factor at period t, $R[t]$ (as shown in Fig. 3). When $R[t]$ is below 1, $PS[t] = A_d$. This condition can be imposed through the use of additional binary decision variables $b_A[t]$ and a sufficiently large number M. $PS[t]$ must always be greater than or equal to A_d. $R[t]$ must be greater than or equal to 1 or $PS[t]$ must be less than or equal to A_d:

$$\forall t, PS[t] \geq A_d \tag{C.13}$$

$$\forall t, R[t] + M\cdot b_A[t] \geq 1 \tag{C.14}$$

$$\forall t, PS[t] \leq A_d + M\cdot(1 - b_A[t]) \tag{C.15}$$

When $R[t]$ is above Rb_d, $PS[t] = B_d$. A similar logic can be applied and results in the following constraints that use M and the additional binary decision variables $b_B[t]$:

$$\forall t, PS[t] \leq B_d \tag{C.16}$$

$$\forall t, R[t] - M\cdot b_B[t] < Rb_d \tag{C.17}$$

$$\forall t, PS[t] \geq B_d - M\cdot(1 - b_B[t]) \tag{C.18}$$

When $R[t]$ is between 1 and Rb_d, $PS[t]$ grows linearly between A_d and B_d. We present this constraint in logical form below.

$$\forall t, if(1 \leq R[t] \leq Rb_d), PS[t] = A_d + \frac{B_d - A_d}{Rb_d - 1}\cdot(R[t] - 1) \tag{C.19}$$

We note that C.19 is non-linear. We show how we linearize it in Appendix C.1.

The R-factor starts initially with a value of 0. Afterwards, it is the ratio of accumulated company revenues minus the accumulated operational expenditures to the accumulated capital expenditures until the previous period. The company revenues at each period t are its profit petroleum $PP_c[t]$ and its cost petroleum $CP[t]$.

$$R[1] = 0 \tag{C.20}$$

$$\forall t > 1, R[t] = \sum_{n=1}^{t-1} \frac{PP_c[n] + CP[n] - OPEX[n]}{CAPEX[n]} \tag{C.21}$$

Each OGC is optimizing its bid based on a certain expected scenario. Yet, the OGC wants to maximize its upside in case a better scenario ends up occurring. To maximize the upside the company must minimize B_d or equivalently minimize Rb_d. We present below the constraints that minimize Rb_d. The minimum Rb_d corresponds to setting it equal to the maximum value that $R[t]$ reaches. This can be written using M and the binary variables $b_{Rb}[t]$ according to the following constraints. C.22 guarantees that Rb_d is greater than or equal to all $R[t]$. C.23 and C.24 guarantee that for one and only one period t, $Rb_d \leq R[t]$.

$$\forall t, Rb_d \geq R[t] \tag{C.22}$$

$$\forall t, Rb_d \leq R[t] + M \cdot (1 - b_{Rb}[t]) \tag{C.23}$$

$$\sum_{t=1}^{T} b_{Rb}[t] = 1 \tag{C.24}$$

The renewable contribution in period t $RC[t]$ corresponds to the product of the RC_d parameter and the company profit petroleum $PP_c[t]$:

$$\forall t, RC[t] = RC_d \cdot PP_c[t] \tag{C.25}$$

The above constraint is non-linear as the RC_d decision variable is multiplied by the intermediate decision variables $PP_c[t]$. Similar to the CP_d parameter, we linearize this constraint by considering RC_d as an input parameter. We solve the resulting linear program several times by varying RC_d over its range of possible values $0 \leq RC_d \leq 10\%$ by increasing it one percentage point at a time. In total, we end up with 11 possible RC_d values. Combining the 66 different possible values for CP_d with the 11 possible values for RC_d, we end up with a total of 726 linear programs that must be solved to compute the optimal biddable items at one percentage point precision for the RC_d and the CP_d decision variables.

In order to compute the tax collected every period t, $tax[t]$, the taxable amount $TA[t]$ must be determined. At any period, the taxable amount is composed of the company revenues minus the company costs. The company costs are composed of the depreciated capital expenditures over a five-year period as stipulated by the Lebanese regulations, the operational expenditures and the renewable contributions. Additionally, the Lebanese system stipulates that losses in a certain period are carried forward indefinitely. These conditions can be imposed according to the following constraints expressed in logical form. We show their linear equivalents in Appendix C.2.

$$\forall t > 1, if(TA[t-1] \geq 0), TA[t] = PP_c[t] + CP[t] - DepCAPEX[t] - OPEX[t] - RC[t] \tag{C.26}$$

$$\forall t > 1, if(TA[t-1] < 0), TA[t] = TA[t-1] + PP_c[t] + CP[t] - DepCAPEX[t] - OPEX[t] - RC[t] \tag{C.27}$$

Additionally, at $t = 1$, the taxable amount is 0.

$$TA[1] = 0 \tag{C.28}$$

$tax[t]$ is calculated accordingly where CIT is the corporate income tax rate. We show the linear representation of C.29 in Appendix C.3.

$$\forall t > 1, tax[t] = max(CIT \cdot TA[t], 0) \tag{C.29}$$

The net petroleum revenues that the company is making at period t $PR_c[t]$ is computed accordingly:

$$\forall t, PR_c[t] = PP_c[t] + CP[t] - tax[t] - CAPEX[t] - OPEX[t] - RC[t] \tag{C.30}$$

The equivalent value at period t that the $RC[t]$ investments generate ($RCVal[t]$) is the product of $RC[t]$ by the return factor of the renewable energy investments RF:

$$\forall t, RCVal[t] = RF \cdot RC[t] \tag{C.31}$$

Where $RF = \frac{RoR_{ren} \cdot (1+RoR_{ren})^{Tr}}{(1+RoR_{ren})^{Tr-1}} \cdot \frac{(1+i_{cRen})^{Tr-1}}{i_{cRen} \cdot (1+i_{cRen})^{Tr}}$.

The constraint on the company achieving its rate of return requirement is the following:

$$\sum_{t=1}^{t=T} \frac{PR_c[t] + RCVal[t]}{(1+i_c)^t} = 0 \tag{C.32}$$

Appendix C.1. Linearizing C.19

In order to linearize C.19, we approximate the linear growth of $PS[t]$ over the $R[t]$ range $[1, Rb_d]$ by S different discrete steps. In practice, Rb_d is generally below 5. After running several experiments, we find out that approximating the straight line by $S = 50$ discrete steps provides a very accurate approximation. Accordingly, C.19 can be replaced by the following constraints expressed in logical form where s is the step index over the range $[1, S]$.

$$\forall t \forall s, if\left(R[t] \geq 1 + \frac{s-1}{S} \cdot (Rb_d - 1)\right), PS[t] \geq A_d + \frac{s}{S+1} \cdot (B_d - A_d) \tag{C.33}$$

$$\forall t \forall s, if\left(R[t] \leq 1 + \frac{s}{S} \cdot (Rb_d - 1)\right), PS[t] \leq A_d + \frac{s}{S+1} \cdot (B_d - A_d) \tag{C.34}$$

C.33 can be written in linear form accordingly using the binary decision variables $b_{R1}[t][s]$ and M:

$$\forall t \forall s, R[t] - M \cdot b_{R1}[t][s] < 1 + (Rb_d - 1) \cdot \frac{s-1}{S} \tag{C.35}$$

$$\forall t \forall s, PS[t] \geq A_d + (B_d - A_d) \cdot \frac{s}{S+1} - M \cdot (1 - b_{R1}[t][s]) \tag{C.36}$$

C.34 can be written in linear form accordingly using the binary decision variables $b_{R2}[t][s]$ and M:

$$\forall t \forall s, R[t] + M \cdot b_{R2}[t][s] \geq 1 + (Rb_d - 1) \cdot \frac{s}{S} \tag{C.37}$$

$$\forall t \forall s, PS[t] \leq A_d + (B_d - A_d) \cdot \frac{s}{S+1} + M \cdot (1 - b_{R2}[t][s]) \tag{C.38}$$

Additionally, to guarantee that the transformation of the straight line into discrete steps does not cause undesired discontinuities, the following three constraints are added:

$$\forall t, b_A[t] + b_{R1}[t][1] = 1 \tag{C.39}$$

$$\forall t, b_B[t] + b_{R2}[t][S] = 1 \tag{C.40}$$

$$\forall t, \forall s < S, b_{R2}[t][s] + b_{R1}[t][s+1] = 1 \tag{C.41}$$

Thus, the linearized version of C.19 is constraints C.35 - C.41.

Appendix C.2. Linearizing C.26 and C.27

Constraint C.26 is equivalent to the following constraints:

$$\forall t > 1, TA[t] \leq PP_c[t] + CP[t] - DepCAPEX[t] - OPEX[t] - RC[t] \tag{C.42}$$

$$\forall t > 1, if(TA[t-1] \geq 0), TA[t] \geq PP_c[t] + CP[t] - DepCAPEX[t] - OPEX[t] - RC[t] \tag{C.43}$$

C.43 can be written in linear form accordingly using the binary decision variables $b_{TA}[t]$ and M:

$$\forall t > 1, TA[t-1] - M \cdot b_{TA}[t] \leq 0 \tag{C.44}$$

$$\forall t > 1, TA[t] \geq PP_c[t] + CP[t] - DepCAPEX[t] - OPEX[t] - RC[t] + M \cdot (b_{TA}[t] - 1) \tag{C.45}$$

Accordingly, C.26 is equivalent to the linear constraints C.42, C.44 and C.45.

Similarly, C.27 can be represented linearly by the following constraints using the binary decision variables $b_{TA}[t]$ and M:

$$\forall t > 1, TA[t-1] + M \cdot (1 - b_{TA}[t]) \geq 0 \tag{C.46}$$

$$\forall t > 1, TA[t] \leq PP_c[t] + CP[t] - DepCAPEX[t] - OPEX[t] - RC[t] + TA[t-1] + M \cdot b_{TA}[t] \tag{C.47}$$

$$\forall t > 1, TA[t] \geq PP_c[t] + CP[t] - DepCAPEX[t] - OPEX[t] - RC[t] + TA[t-1] - M \cdot b_{TA}[t] \tag{C.48}$$

Accordingly, C.27 is equivalent to the linear constraints C.46-C.48.

Appendix C.3. Linearizing C.29

C.29 is equivalent to the following constraints:

$$\forall t, tax[t] \geq 0 \tag{C.49}$$

$$\forall t, tax[t] \geq CIT \cdot TA[t] \tag{C.50}$$

$$\forall t, if(TA[t] \geq 0), tax[t] \leq CIT \cdot TA[t] \tag{C.51}$$

$$\forall t, if(TA[t] < 0), tax[t] \leq 0 \tag{C.52}$$

C.51 can be written in linear form accordingly using the binary decision variables $b_{tax}[t]$ and M:

$$\forall t, TA[t] - M \cdot b_{tax}[t] \leq 0 \tag{C.53}$$

$$\forall t, tax[t] \leq CIT \cdot TA[t] + M \cdot (1 - b_{tax}[t]) \tag{C.54}$$

Similarly, C.52 can be written in linear form accordingly:

$$\forall t, TA[t] + M \cdot (1 - b_{tax}[t]) \geq 0 \tag{C.55}$$

$$\forall t, tax[t] \leq M \cdot b_{tax}[t] \tag{C.56}$$

Accordingly C.29 is equivalent to the linear constraints C.49, C.50, C.53-C.56.

Appendix C.4. Complete Linear Model

This subsection presents the complete optimization model in its linear form. The linear form of the optimization model is:

$$\max\left(\sum_{t=1}^{T}\frac{TGT[t]+\alpha.RC[t]}{(1+i_s)^t}\right)$$
$$\begin{aligned} &s.t: \\ &C.4-C.6 \\ &C.11-C.18 \\ &C.20-C.25 \\ &C.28 \\ &C.30-C.32 \\ &C.35-C.42 \\ &C.44-C.50 \\ &C.53-C.56 \end{aligned} \tag{C.57}$$

CP_d and RC_d are treated as input parameters and the described linear model is solved 726 times by varying CP_d over the range $[0, 65\%]$ one percentage point at a time and RC_d over the range $[0, 10\%]$ one percentage point at a time and taking all the possible combinations.

The decision variables of the model are displayed in Table C.9. The state-related input parameters are displayed in Table C.10. The input parameters that correspond to each oil and gas scenario are displayed in Table C.11 while those that are specific to each company are displayed in Table C.12. Additional intermediate input parameters are listed in Table C.13.

The sufficiently large number M is used in the following constraints: C.14, C.15, C.17, C.18, C.23, C.35-C.38, C.44-C.48, C.53-C.56. Table C.14 shows how large M must be to for it to be sufficiently large for each group of constraints. Accordingly, M must satisfy the following:

$$M \geq 1 \tag{C.58}$$

$$M \geq \max_t(R[t]) \tag{C.59}$$

$$M \geq \max_t(PP_c[t]+CP[t]) \tag{C.60}$$

A sufficiently large value of M that depends on the input parameters and that satisfies the above can be equal to the maximum periodic total revenues that the upstream project is generating:

$$M = \max_t\left(Prod_g[t]\cdot Price_g[t]+Prod_o[t]\cdot Price_o[t]\right) \tag{C.61}$$

The CPU runtimes when running this optimization model on IBM CPLEX Solver for the input parameters of $OGC1$, $OGC2$ and $OGC3$ on a personal computer with 8 gigabytes of RAM and a quad-core 2.8 GHz processor are: 2723, 3561 and 3459 s respectively.

Table C.9
Model decision variables, $t \in [1, T], s \in [1, S]$, t and s are integers

Decision Variable	Description
A_d	Minimum State Share of Profit Petroleum
B_d	Maximum State Share of Profit Petroleum
Rb_d	R-factor Trigger Point for State Share to Reach B_d
$TGT[t]$	Total Government Take at Period t
$PP_s[t]$	State Profit Petroleum at Period t
$PP_c[t]$	Company Profit Petroleum at Period t
$PS[t]$	State Profit Petroleum Share at Period t
$R[t]$	R-factor at Period t
$RC[t]$	Renewable Contribution at Period t
$TA[t]$	Taxable Amount at Period t
$tax[t]$	Taxes at Period t
$PR_c[t]$	Company Net Petroleum Revenues at Period t
$RCVal[t]$	Value of Returns on Investment of $RC[t]$ at Period t
$b_A[t]$, $b_B[t]$, $b_{Rb}[t]$, $b_{R1}[t][s]$, $b_{R2}[t][s]$, $b_{TA}[t]$, $b_{tax}[t]$	Additional Binary Decision Variables at Period t and Step s

Table C.10
State-related input parameters

Input	Description
$\alpha = 0.36$	
$\rho_g = 4\%$	Royalty on Natural Gas
$\rho_o = 5\%$	Royalty on Oil for all Scenarios
$CIT = 20\%$	Corporate Income Tax
$T = 30$ years	Oil and Gas Project Life
$i_c = 8\%$	State Discount Rate

(continued on next page)

Table C.10 (*continued*)

Input	Description
$RoR_{ren} = 5\%$	RoR of Renewable Energy Projects in Lebanon
$T_r = 20$ years	Renewable Energy Project Life

Table C.11
Inputs from oil and gas scenarios

Input	Description
$Price_g$	Profile of Natural Gas Prices
$Price_o$	Profile of Oil Prices
$Prod_g$	Natural Gas Production Profile
$Prod_o$	Oil Production Profile
$CAPEX$	Profile of Capital Expenditures
$OPEX$	Profile of Operational Expenditures

Table C.12
Inputs related to companies

Input	Description
i_c	Company Oil and Gas RoR
i_{cRen}	Company Renewable Energy RoR

Table C.13
Intermediate input parameters used in model

Intermediate Input	Description
$\rho[t]$	Total Royalty at Period t
$DP[t]$	Disposable Petroleum at Period t
$CP[t]$	Cost Petroleum at Period t
$DepCAPEX[t]$	Depreciated CAPEX at Period t
RF	$\frac{(A/P, RoR_{ren}, T_r)}{A/P, i_{cRen}, T_r}$

Table C.14
Minimum values of M

Value of M	Constraints for which M is sufficiently large
1	C.14, C.15, C.17, C.18, C.36, C.38
$\max_t(R[t])$	C.23, C.35, C.37
$\max_t(PP_c[t] + CP[t])$	C.44-C.48, C.53-C.56

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