



University of  
Stavanger

**Faculty of Science and Technology**

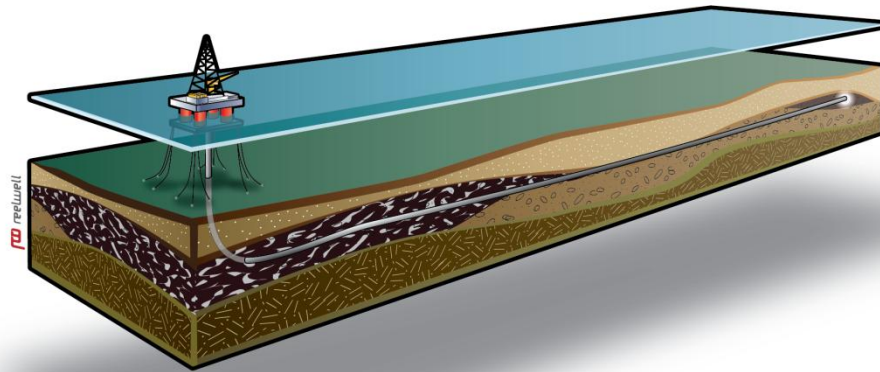
## **MASTER'S THESIS**

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# **“Developing a value case model for the Reelwell Drilling Method”**

by

**Benjamin Lung-Tze Liew**



**A Master’s Thesis**

**Presented to the Faculty of Science and Technology**

**University of Stavanger**

**In fulfilment of the Requirements for the Degree**

**Master of Science**



## Summary

The objective of this thesis has been to develop a value case model in Excel for analyzing the potential economic benefits of the Reelwell Drilling Method (RDM). The value case model was intended for use within Reelwell and as a way of showing their customers the potential of RDM. RDM is a new drilling technology which could potentially expand the horizontal drilling reach from 10 km to 20 km. A value case is defined in this thesis as a collection of Excel-based models which analyze different applications of RDM.

The initial scope of the value case model was to analyze two specific cases: the first model, *model CC* (cost comparison), compares the cost and time usage when using RDM and conventional drilling equipment on the same well. The second model, *model FDA* (field development analysis), analyzes RDM in a field development setting. RDM is used in an extended reach well and compared to a subsea installation.

The value case model was developed according to the agile project management methods. Agile project management methods focus in being able to handle scope changes, and are suitable for projects where the solution is not clear-cut. The development phase of the thesis was structured in seven 2 weeks development cycles. A lot of time and research was put into making the Excel-models easy to use and have an intuitive layout. The result is an Excel-based model that behaves more like a custom-made program than an Excel spreadsheet.

Later the scope was redefined in collaboration with Reelwell to that the value case model should be able to compare any two drilling programs, and be able to compare any two field development investment options. The benefit of this was that the Excel models would not have to be rebuilt if different cases than those in the initial scope were to be analyzed.

The final value case model is capable of analyzing any two drilling programs and any two field development investment options. In other words the model is capable of high-level feasibility studies, compilation of information at an early decision-making stage and high-level cost comparisons of drilling programs and field development investment options. As such, the value case model fulfilled the re-defined scope. With respect to the objective of the thesis the value case model is only suited for use within Reelwell, and is not suitable for use towards customers. Reelwell deemed the added flexibility to be more beneficial than a commercial product at the end of the thesis. The value case model is functionally complete, but some work remains in order for it to be a commercial product.

## **Preface**

This master's thesis marks the end of a long and interesting journey at the University of Stavanger. The thesis was written in cooperation with Reelwell, and is the first time I have developed a product for an oil and gas service company.

I would like to use this opportunity to thank the people at Reelwell for their support and willingness to help me with this thesis. I want especially to thank Mette Alhaug, Arne Wyller Christensen, Einar Christensen and Ove Hole and Arnfinn Nergaard at Reelwell for valuable input on how to improve the model.

Thanks are also given to Tormod Svensen for helping me get a basic overview of the complexity of the offshore drilling processes and Bjørn Schmidt for assisting with understanding how cost estimates are done.

At the University of Stavanger I would like to thank Hans Jacob Fevang, the Head of the Department of Industrial Economics, for his willingness to help me with questions related to Excel and economic theory, and professor Petter Osmundsen for accepting to be the faculty supervisor of an unconventional master's thesis and always being quick to reply when help was needed.

Lastly, I give a big thank you to fellow student Øystein Viken whom I have written this thesis with. Together we have accomplished what was initially seen as improbable – an Excel-based model which will become a commercial product in the near future.

~ Benjamin L. Liew, Stavanger 14<sup>th</sup> June 2012

# Contents

|  |            |
|--|------------|
| <b>SUMMARY</b> .....   | <b>II</b>  |
| <b>PREFACE</b> .....   | <b>III</b> |
| <b>CONTENTS</b> .....  | <b>IV</b>  |
| <b>LIST OF TABLES AND FIGURES</b> .....  | <b>VI</b>  |
| <b>ABRIDGEMENTS, SPECIFICATION OF WORDS AND CONVENTIONS</b> .....              | <b>IX</b>  |
| <b>1.0 INTRODUCTION</b> .....  | <b>1</b>   |
| 1.1 DEFINITION AND DELIMITATION OF OBJECTIVE AND SCOPE .....                   | 1          |
| 1.2 BACKGROUND FOR THE THESIS .....  | 2          |
| 1.3 REELWELL.....  | 3          |
| 1.4 THE STRUCTURE OF THE THESIS.....   | 3          |
| <b>2. PROJECT MANAGEMENT AND PLANNING</b> .....                                | <b>4</b>   |
| <b>3. THEORY - DRILLING:</b> .....   | <b>7</b>   |
| 3.1 DRILLING – AN INTRODUCTION .....   | 7          |
| 3.1.1 <i>The drilling process</i> .....  | 7          |
| 3.1.2 <i>Drilling problems</i> .....   | 9          |
| 3.1.3 <i>History of horizontal drilling</i> .....                              | 10         |
| 3.1.4 <i>Directional and horizontal drilling</i> .....                         | 10         |
| 3.1.5 <i>Complex wells</i> .....   | 11         |
| 3.1.6 <i>Subsea Wells</i> .....  | 11         |
| 3.2 THE REELWELL DRILLING METHOD.....  | 13         |
| 3.2.1 <i>RDM solutions to drilling problems in long horizontal wells</i> ..... | 15         |
| 3.2.1 <i>Advantages of extended reach drilling with RDM</i> .....              | 19         |
| 3.3 RECOVERY RATES. ....   | 20         |
| 3.4 VALIDATION OF DATA .....   | 21         |
| 3.5 WELL COST ESTIMATION MODEL .....   | 22         |
| 3.6 DETERMINING WHICH COST FACTORS TO INCLUDE WHEN ESTIMATING WELL COSTS. .... | 23         |
| 3.7 P10, P50 AND P90 .....   | 25         |
| <b>4. THEORY – ECONOMICS</b> .....   | <b>27</b>  |
| 4.1 CAPITAL BUDGETING TECHNIQUES. ....   | 27         |
| 4.1.1 <i>Estimating Net Present Values</i> . ....                              | 27         |
| 4.1.2 <i>Estimating Internal Rates of Return</i> . ....                        | 28         |
| 4.1.3 <i>Calculating the NPV and IRR in the excel model</i> .....              | 29         |
| 4.2 THE TAXATION OF PETROLEUM ACTIVITIES. ....                                 | 30         |
| 4.3 HOW TO MODEL OIL AND GAS PRICES. ....                                      | 31         |
| 4.4 ALTERNATIVE SOLUTIONS TO THE MODEL.....                                    | 33         |
| 4.4.1 <i>Econometrics</i> .....  | 33         |
| 4.4.2 <i>The generalized functional model</i> .....                            | 33         |
| 4.4.3 <i>Exclusion of the alternate solutions</i> .....                        | 33         |
| <b>5. EXCEL</b> .....  | <b>34</b>  |
| <b>6. THE VALUE CASE MODEL IN EXCEL</b> .....                                  | <b>35</b>  |
| 6.1 AN INTRODUCTION TO THE MODEL.....  | 36         |

|  |           |
|--|-----------|
| 6.2 DESCRIBING THE FINAL MODELS .....  | 38        |
| 6.2.1 Main Menu, FAQ and Toolbars.....                                       | 38        |
| 6.2.2 Model CC – Comparing RDM with conventional equipment .....             | 39        |
| 6.2.3 Model FDA – Comparing an ER well (RDM) with a subsea installation..... | 43        |
| 6.3 THE DEVELOPMENT CYCLES .....   | 53        |
| 6.3.1 Development cycle 1.....   | 54        |
| 6.3.2 Development cycle 2.....   | 54        |
| 6.3.3 Development cycle 3.....   | 55        |
| 6.3.4 Development cycle 4.....   | 56        |
| 6.3.5 Development cycle 5.....   | 58        |
| 6.3.6 Development cycle 6.....   | 59        |
| 6.3.7 Development cycle 7.....   | 60        |
| <b>7. DISCUSSION.....</b>  | <b>61</b> |
| 7.1 WHAT CAN THE MODELS ACTUALLY DO? .....                                   | 61        |
| 7.2 USAGE AND LIMITATIONS OF THE MODEL .....                                 | 61        |
| 7.3 POST-THESIS DEVELOPMENT OF THE MODEL .....                               | 63        |
| 7.3.1 On copyright and usage of the model.....                               | 63        |
| 7.3.2 General ideas for continued work .....                                 | 63        |
| 7.3.3 Continued development for Reelwell .....                               | 63        |
| <b>8. CONCLUSION .....</b>   | <b>65</b> |
| <b>9. REFERENCES .....</b>   | <b>66</b> |
| <b>APPENDIX A – RECOMMENDED READING .....</b>                                | <b>70</b> |
| <b>APPENDIX B – OFFSHORE INSTALLATIONS.....</b>                              | <b>71</b> |
| <b>APPENDIX C – DRILLING PROBLEMS .....</b>                                  | <b>73</b> |
| <b>APPENDIX D - VALUE CASE MODEL SCREENSHOTS.....</b>                        | <b>76</b> |

## List of tables and figures

### List of tables

|   |         |
|---|---------|
| Table 1: Cost-elements in offshore well (Reelwell, 2012a)                       | Page 23 |
| Table 2: Cost elements in subsea (Reelwell, 2012b)                              | Page 24 |
| Table 3: Taxation of petroleum activities in Norway (Ministry of Finance, 2012) | Page 30 |

### List of figures

|   |         |
|---|---------|
| Figure 2.1: The four project management models (Wysocki, 2009, p. 300)  | Page 4  |
| Figure 2.2: Modified Adaptive Project Framework (Wysocki, 2009, p. 405)   | Page 5  |
| Figure 3.1: Different types of drill bits (petroleumonline, 2012)   | Page 8  |
| Figure 3.2. Horizontal well design and S-shaped well design   | Page 10 |
| Figure 3.3 Illustration of a subsea template with pipelines and umbilical (Oilinfo, 2010)   | Page 12 |
| Figure 3.4: RDM system overview. (Illustration: Reelwell)   | Page 13 |
| Figure 3.5 Dual drill string used in a RDM test run in Canada. (Photo: Reelwell)  | Page 14 |
| Figure 3.6: RDM system with piston. (Illustration: Reelwell)  | Page 14 |
| Figure 3.7: ECD, dynamic gradient, (Illustration: Reelwell)   | Page 15 |
| Figure 3.8. In horizontal wells cuttings tend to deposit in the lower half of the wellbore. (Illustration: Reelwell)  | Page 15 |
| Figure 3.9. Cutting transportation through the inner drill string using the RDM leaving no cuttings in the horizontal wellbore. (Illustration: Reelwell)                      | Page 16 |
| Figure 3.10 Pressurized piston creating additional WOB. (Illustration: Reelwell)  | Page 17 |
| Figure 3.11 – Increased extended drilling reach with RDM (Illustration: Reelwell)   | Page 19 |
| Figure 3.12: Sample space   | Page 25 |
| Figure 3.13: Fixed reservoir size   | Page 25 |
| Figure 3.14: Sample space matrix  | Page 26 |
| Figure 4.1: Crude Oil Prices (WTRG, 2011)   | Page 32 |
| Figure 5.1 – Excel 2010 logo (Microsoft Office (2012))  | Page 34 |
| Figure 5.2 – Print Screen from a blank Excel spreadsheet.   | Page 34 |
| Figure 6.1. Showing the functional structure of the value case model  | Page 36 |
| Figure 6.2. The toolbar for model CC. Each of the blue boxes is a direct link to the given sheet. Activated sheets are shown as green, e.g. <i>Input: Drilling programs</i> . | Page 38 |
| Figure 6.3. The toolbar for model FDA. Each of the blue boxes is a direct link to the given sheet.  | Page 38 |
| Figure 6.4a - Sheet <i>Input: Drilling Programs</i>   | Page 39 |
| Figure 6.4b - Sheet <i>Input: Drilling Programs</i>   | Page 40 |
| Figure 6.5 – Conventional drilling reach (Illustration. Reelwell)   | Page 43 |

|  |         |
|--|---------|
| Figure 6.6 - Extended well using RDM (Illustration. Reelwell)  | Page 43 |
| Figure 3.7 – Subsea installation with tieback to the platform (Illustration. Reelwell)   | Page 43 |
| Figure 6.8a – Sheet <i>ProdGraph</i> showing oil production on the Sorre field. The sheet also demonstrates a fictional oil production forecast through 2030 with both RDM and Subsea production totals. | Page 47 |
| Figure 6.8b - Sheet <i>ProdGraph</i> explained   | Page 48 |
| Figure 6.8c - Hiding the historic production in the sheet <i>ProdGraph</i>   | Page 48 |
| Figure 6.8d - Hiding the historic production in the sheet <i>ProdGraph</i> with the settings explained.  | Page 49 |
| Figure 6.8e – Resolving the scale problems in the sheet <i>ProdGraph</i> by showing the added and lost production relative to the forecast. This solves scale problems as seen in figure 6.8e.           | Page 50 |
| Figure 6.8f – View options explained in the sheet <i>ProdGraph</i> for showing added production only.  | Page 50 |
| Figure 7.1: Sample space (Reservoir size, Rate of Recovery)  | Page 62 |
| Figure C1 – Cross section of a well hole where differential pressure between the mud column and the formation presses the drill string against the side of the well.                                     | Page 73 |
| Figure D1.1a – <i>Main menu</i> shows an overview of all the sheets in the model.  | Page 77 |
| Figure D1.1b – <i>Main menu</i>  | Page 78 |
| Figure D1.1c – The flowchart in the sheet <i>Main Menu</i> explained.  | Page 79 |
| Figure D1.2 – The sheet <i>FAQ</i> shows a list of possible problems and questions the user may encounter with possible solutions.   | Page 80 |
| Figure D2.1a – <i>Instructions CC</i>  | Page 81 |
| Figure D2.1b – <i>Instructions CC</i>  | Page 82 |
| Figure D2.2a – <i>Input: Fixed costs and rates</i>   | Page 83 |
| Figure D2.2b - <i>Input: Fixed costs and rates</i>   | Page 84 |
| Figure D2.2c – <i>Input: Fixed costs and rates</i>   | Page 85 |
| Figure D2.2d - <i>Input: Fixed costs and rates</i>   | Page 86 |
| Figure D2.3a – <i>Results: Cost &amp; Time</i>   | Page 87 |
| Figure D2.3b – <i>Results: Cost &amp; Time</i>   | Page 88 |
| Figure D2.3c – <i>Results: Cost &amp; Time</i> expanded to show P10 and P90.   | Page 89 |
| Figure D2.3d – <i>Results: Cost &amp; Time</i> expanded to show the cost-breakdown.  | Page 90 |
| Figure D2.3e – <i>Results: Cost &amp; Time</i> expanded to show both P10 and P90, and cost-breakdown   | Page 91 |
| Figure D3.1a – <i>Instructions FDA</i> .   | Page 92 |
| Figure D3.1b – <i>Instructions FDA</i> .   | Page 93 |
| Figure D3.2a – <i>Input: Key variables</i> .   | Page 94 |
| Figure D3.2b – <i>Input: Key variables</i> .   | Page 95 |
| Figure D3.2c – <i>Input: Key variables</i> expanded to show a table of yearly dynamic petroleum prices.  | Page 96 |
| Figure D3.2d – <i>Input: Key variables</i> expanded to show a table of yearly dynamic petroleum prices.  | Page 97 |



|  |          |
|--|----------|
| Figure D3.3a – <i>Input: Estimate cost.</i>  | Page 98  |
| Figure D3.3b – <i>Input: Estimate cost.</i> In order to use the more detailed “cost-breakdown” you must check the option button. | Page 99  |
| Figure D3.3c – <i>Input: Estimate cost</i> with option for cost-breakdown enabled.   | Page 100 |
| Figure D3.3d – <i>Input: Estimate cost</i> showing P10 and P90 cost values.  | Page 101 |
| Figure D3.4a – The sheet menu for <i>Input: Production profiles.</i>   | Page 102 |
| Figure D3.4b - The sheet menu for <i>Input: Production profiles.</i>   | Page 103 |
| Figure D3.4c - <i>Input: Production profiles</i> showing a production profile for P50 scenario.                                  | Page 104 |
| Figure D3.4d - <i>Input: Production profiles</i> showing a production profile for P50 scenario.                                  | Page 105 |
| Figure D3.5a - The sheet menu for <i>Input: Cash flows.</i>  | Page 106 |
| Figure D3.5b - The sheet menu for <i>Input: Cash flows.</i>  | Page 107 |
| Figure D3.5c - <i>Input: Cash flows.</i>   | Page 108 |
| Figure D3.5d - <i>Input: Cash flows.</i>   | Page 109 |
| Figure D3.6a – <i>Results: NPV.</i>  | Page 110 |
| Figure D3.6b – <i>Results: NPV.</i>  | Page 111 |
| Figure D3.6c – <i>Results: NPV</i> expanded to view yearly cash flows for RDM and SubSea.  | Page 112 |
| Figure D3.6d – The production section of <i>Results: NPV</i> explained.  | Page 113 |
| Figure D3.6e - The NPV section of <i>Results: NPV</i> explained.   | Page 114 |

## **Abridgements, specification of words and conventions**

| <b><u>Abridgement</u></b> | <b><u>Explanation</u></b>        |
|---------------------------|----------------------------------|
| AFE                       | Approved For Expenditure         |
| APM                       | Agile Project Management         |
| BOP                       | Blowout Preventer                |
| CAPM                      | Capital Asset Pricing Model      |
| DDS                       | Dual Drill String                |
| DFV                       | Dual Float Valve                 |
| ECD                       | Equivalent Circulation Density   |
| EOW                       | End of Well                      |
| ER                        | Extended Reach                   |
| ERD                       | Extended Reach Drilling          |
| FAQ                       | Frequently Asked Questions       |
| FCU                       | Flow Control Unit                |
| HPHT                      | High-Pressure, High-Temperature  |
| IRR                       | Internal Rate of Return          |
| JIP                       | Joint Industry Project           |
| MPx                       | Emertxe Project Management       |
| NGL                       | Natural-Gas Liquids              |
| NPV                       | Net Present Value                |
| P&A                       | Plug and Abandon                 |
| PV                        | Present Value                    |
| RDM                       | Reelwell Drilling Method         |
| SCM                       | Standard Cubic Meter             |
| TDA                       | Top Drive Adapter                |
| TPM                       | Traditional Project Management   |
| WACC                      | Weighted Average Cost of Capital |
| WOB                       | Weight-on-bit                    |
| xPM                       | Extreme project Management       |

## **Specification of words**

Annulus – The space between the drill string and the hole.

CC – Cost Comparison. In this thesis CC is used to describe the case in which the cost of two drilling programs are compared.

FDA – Field Development Analysis. In this thesis FDA is used to describe the case where the field development options extended reach drilling with RDM and subsea installation are compared.

Field – Oil and gas field

Investment option – One of the two investments that are analyzed in the excel model FDA. In this thesis the investment options are limited to an extended reach well using the Reelwell Drilling Method and a subsea installation.

Reservoir – Oil and gas reservoir

Sheet – A spreadsheet page in Excel

SubSea – Abbreviation of subsea installation

## **Conventions**

All the names of the excel spreadsheets in the models will be written in italics. E.g. *Input: Production profiles* and *Results: NPV*. Likewise will all specific components in the excel spreadsheets that are named be written italics.

The model allows for choosing between the metric system and the US customary units. This thesis uses Oljedirektoratet's unit conversion table (Oljedirektoratet, 2011). The table defines 1 standard cubic meter (scm) of crude oil as 6.29 barrels of crude oil.

## 1.0 Introduction

### 1.1 Definition and delimitation of objective and scope

The objective of this thesis is to develop a value case model in Excel that can analyze the potential economic benefits of the Reelwell Drilling Method (RDM) for Reelwell. A “value case model” is defined in this thesis as a collection of Excel models which analyze different applications of RDM and the potentially added value thereof. The value case model is intended for use within Reelwell and as a way of showing customers the potential in RDM. As such, it is important that the model is easy to use and that the layout is intuitive for the users.

The scope of the value case model was defined together with Reelwell as the following: Develop a value case model that consists of two excel-based models which must be able to analyze the financial benefits or disadvantages when analyzing RDM in two different case studies. These two case studies are defined as:

- a) A direct comparison between RDM and conventional drilling equipment when both types of equipment are used on the same well. This model is named *model CC* (cost comparison)
- b) The comparison between two investment options when an outlying reservoir in a field is considered being developed. RDM will be used to drill an extended reach well from a platform located on the main reservoir, and this will be compared to using a subsea installation. This model is named *model FDA* (field development analysis).

The two models are independent, but will be presented in the same excel-file.

Delimitation: Because developing such a model is very time-consuming, the model will not be applied to real-life case studies. Such studies are beyond the scope of this thesis. Future theses might attempt to apply our model to real-life case studies.

## **1.2 Background for the thesis**

Jostein Aleksandersen, CEO and director of Reelwell, was the lecturer in the subject “Entrepreneurship in technology based companies” in 2011 at the University of Stavanger. At the end of the term Aleksandersen presented a master thesis that Reelwell wanted two students to write. The main focus of the thesis was to make a “Simulation model for value cases when using the Reelwell Drilling Method (RDM)”. I found the concept of making a model for value cases very interesting, especially the fact that this kind of model had not been made before. Øystein Viken and I both told Aleksandersen that we were interested in writing the thesis. After an individual assessment from Reelwell and deciding with Viken that we could indeed form a joint venture – we were given the thesis.

Below follows a short introduction of the authors’ backgrounds:

Benjamin L. Liew: Bachelor’s Degree Program in Mechanical Engineering with focus on economics and materials science. Industrial economics as a 2-year master program with focus on project management and risk evaluation.

Øystein Viken: Bachelor’s Degree Program in Applied Science with focus on materials science. Industrial economics as a 2-year master program with focus on project management and maintenance and operations.

### **1.3 Reelwell**

Reelwell AS is an oil and gas service company which develops drilling technology and provides drilling services. Ola M. Vestavik founded Reelwell in 2004.

Reelwell has developed a new drilling technology which they call “Reelwell Drilling Method” (RDM). RDM is based on a drilling system where a dual drill string is used to transport drilling fluid to the bit via the drill string annulus, and the return flow to the surface is through an inner string (Reelwell, 2012a). The technology used in RDM is explained in chapter 3.2.

Reelwell has won a number of prizes due to RDM: They won the OTC Spotlight Award in 2009, 2010, 2011 and 2012, the ONS 2010 Innovation Award and DnB Nors Regional Innovation Price 2011 (Reelwell, 2012b).

Currently Reelwell is participating in a Joint Industry Project (JIP) on Extended Reach Drilling (ERD) with their partners, Merlin ERD and Signa Engineering Corp., where the aim is to qualify and demonstrate drilling reach beyond 20 km. The JIP started in January 2011, and is expected to last 2 years.

### **1.4 The structure of the thesis**

The final model in this thesis is the sum of the work of two people. As a joint thesis, 50 pct of thesis is common for both, and 50 pct is individual. The thesis consists of nine chapters. Chapter 1 is an introduction to the thesis, and aims to give the reader an overview of the background and structure of this thesis. Chapter 2-5 are chapters about the theory behind this thesis and form the 50 pct of the common material. Chapter 6-8 are about the development of the model, a discussion about the results of the model and a conclusion of this thesis, respectively. Chapters 6-8 form the 50 pct of individual work, but for the sake of completeness both authors’ contributions to the model will be described. Chapter 6.3.1-6.3.7 specifies which author did what. Chapter 9 is devoted to references.

## 2. Project management and planning

A project management plan is always needed whenever a project is to be executed successfully. An agile project management lifecycle was chosen for this project (thesis). This project has the trademarks of an agile project – a not clearly defined final product, and the anticipation of a number of scope changes during the execution of the project.

Wysocki (2009, pp. 301-309) divides the different project management models into four groups:

- a) Traditional Project Management (TPM): Defined by low complexity, few scope change requests, well understood technology infrastructure, low risk and plan-driven.
- b) Agile Project Management (APM): Defined by a critical problem without a known solution, a previous untapped business opportunity, meaningful client involvement and small teams.
- c) Extreme Project Management (xPM): These projects are defined by being research and development projects, and have a very high risk profile.
- d) Emergent Project Management (MPx): Defined as a new technology without a known application, and is in other words a solution in need of a problem to solve.

|      |           | SOLUTION |           |
|------|-----------|----------|-----------|
|      |           | Clear    | Not Clear |
| GOAL | Not Clear | MPx      | xPM       |
|      | Clear     | TPM      | APM       |

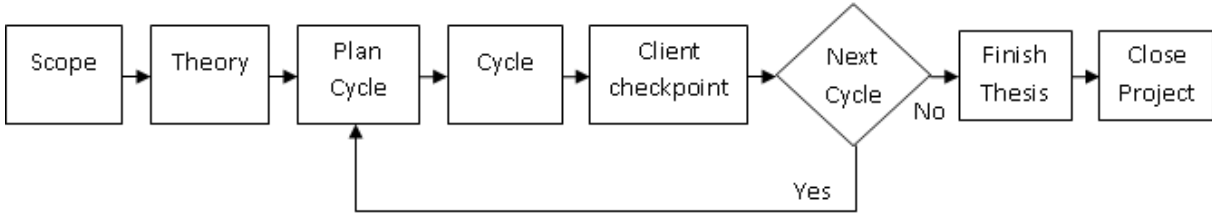
**Figure 2.4: The four project management models (Wysocki, 2009, p. 300)**

Our scope has a clear goal, but the solution is unclear. According to Figure 2.1 (Wysocki, 2009) our project falls into the Agile Project Management group. Within the APM models there are two main approaches – iterative and adaptive models. The main difference between these two models is the degree of uncertainty related to the solution. The iterative models fit projects where most of the solution to the problem is known and a number of scope changes is

expected. The adaptive models however, fit projects where the solution is unclear, and the specifics of the deliverables at the end of the project cannot be identified.

Our project falls clearly within the adaptive models. We know what we are supposed to deliver, a value case model, but the exact nature of the model is not defined. In other words, at the start of the project the final product was unclear – the final product was however, tailored to the client’s specifications and delivered maximum value for the resources spent. The people at Reelwell had an idea of what they wanted solved – a value case model in excel which could show the value of RDM. They did not know what form the final product would take, and it has been a learning process for them, as well as us.

The total timeframe of this project was four and a half months – for both developing the model and writing the thesis. Due to the special nature of a master’s thesis, the project structure we chose was modified from the regular adaptive project management life cycle models (Figure 2.2).



**Figure 5.2: Modified Adaptive Project Framework (Wysocki, 2009, p. 405)**

**Scope:** The initial scope was defined by Reelwell. At first the scope was to develop a value case model with two models in excel, and apply these models on real-life case studies. Later the scope was redefined to exclude the real-life case studies due to the time and resource constraints.

**Theory:** Before the development cycles of the model could begin, theory on the subjects involved in the model was needed. The subjects behind the model are drilling, cost estimation of drilling projects, capital budgeting techniques, modeling oil and gas prices, the Norwegian taxation system and excel programming.

**Development cycle loops:** Each loop consisting of a “Plan Cycle”, “Cycle” and “Client checkpoint” stage. A loop lasted an average of two weeks, and a total of seven cycles was executed - totaling 14 weeks. A detailed description of the development cycles are described in chapter 6.3.1-6.3.7. As with all adaptive projects, client involvement was of great



importance in order to deliver a good product. Due to administrative reasons at Reelwell the client checkpoint was usually the first thing that was executed in a given cycle – i.e. client checkpoint for cycle 1 was executed at the beginning of cycle 2.

Finish Thesis: Complete documentation of model and finish writing the thesis. Hand over the finished model to Reelwell.

Close Project: On the 14<sup>th</sup> June 2012 the thesis was handed in to the University of Stavanger.

### **3. Theory - Drilling:**

#### **3.1 Drilling – An introduction**

These chapters include a brief introduction to offshore drilling and the common problems encountered when drilling offshore. The description of the drilling process, with emphasis on horizontal drilling, will be used as a foundation for the next chapter which explains how RDM differ from the conventional drilling methods, and which problems RDM solve. We realize that it is not possible, nor the purpose of this thesis, to explain in details the complexity of the entire drilling process. Our presentation of relevant drilling theory will focus on the part of the drilling process which takes part in the hole. The “top-side” operations on the rig will not be covered here. A list of recommended books is included in Appendix A for the readers who are unfamiliar with, or wish more information on the drilling process.

The theory on drilling is included in order to give the necessary background information needed in order to understand the costs related to offshore drilling. Furthermore, the model assumes that the user has a certain level of knowledge of the drilling process and field development.

##### **3.1.1 The drilling process**

In the offshore oil and gas industry drilling is the process in which one reaches a reservoir from a rig. An offshore-rig is a structure located off land which is used to drill and/or produce oil or gas. Examples of offshore rigs are barge rigs, submersible rigs, jack-up rigs, semisubmersible rigs, drillships and structure rigs. A short description of each type is found in Appendix B.

A rotary drilling system is used offshore – the drill string is rotated in order to transfer torque to the drill bit. Donohue and Lang (2009, pp. 24-26) classifies drill bits as a drag bit, a rolling cutter bit or a special purpose bit. A drag bit is a bit which uses flat cutter blades to scrape away the rock, and have no moving parts. Diamond bits can also be classified as drag bits as they have no moving parts and drill with a shearing action, but use industrial diamonds instead of cutter blades. The rolling cutter bits on the other hand, contain three cones set with teeth which can roll individually. The roller cone bits vary according to the configuration of the teeth and type of bearing used to join the bit body and cones. The cones move by virtue of contact with the formation. Special purpose bits are bits which are made for a specific need

such as hole openers. Hole openers are used to enlarge or maintain the hole size. See Figure 3.1 for an illustration of the different bits.

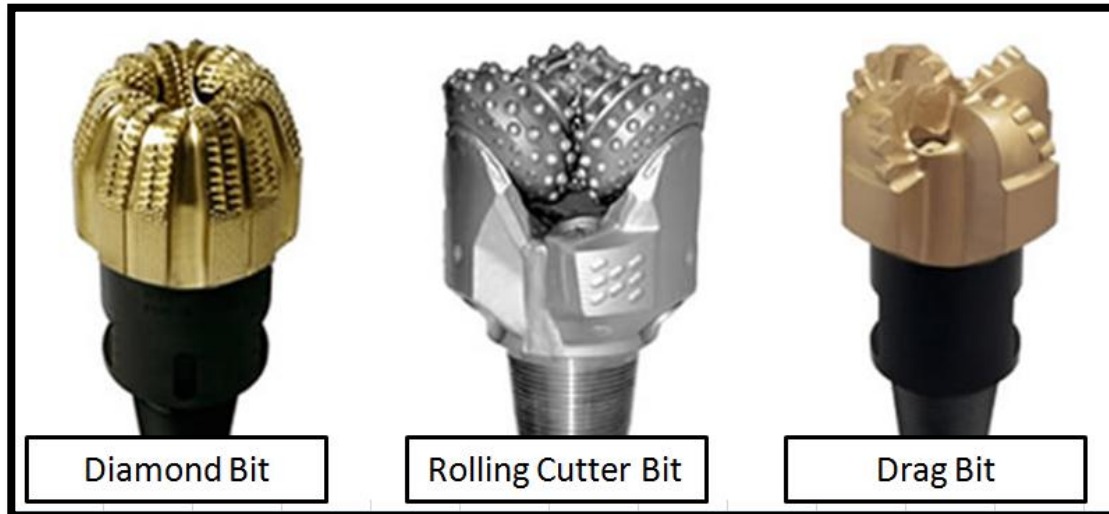


Figure 3.1: Different types of drill bits (petroleumonline, 2012)

No matter which bit is used, there is a need to flush away cuttings and maintain pressure stability in the well. This is obtained by circulating drilling fluids (mud) down the drill string, out through the nozzles in the bit, then back to the surface through the annulus (the space between the drill string and the hole) (Conaway, 1999, p. 105). The main functions of mud are:

- Flush away cuttings, cleaning the rock surface and thereby increasing the bit's penetration rate.
- Lubricating and cooling the bit in order to prolong the bit's useful life.
- Reduce friction between the drill string and the hole.
- Seal off permeable formations in order to prevent mud loss, and equalize the pressure in the hole to that of the formation in order to prevent blowout or formation damage.

The pressure range is defined as the pressure range which does not cause formation damage or result in kicks or blowouts. If the pressure is higher than the formation pressure formation damage will occur. When the pressure is below the formation pressure, formation fluid will be forced up the annulus (called a "kick") and in worst case scenario leads to loss of control of the well (Donohue and Land, 1986, p. 20). This pressure range is called the "pressure window" (Vestavik, Syse and Aleksandersen, 2010, p.4).

When drilling a hole, a casing program is followed. This means that once the hole reaches a certain depth, casing needs to be set before drilling in the hole can be continued. Casing strings are composed of multiple large-diameter steel pipes which are screwed together, and cemented into place in the hole. The purpose of the casing is to protect the hole from the mud pressure as the mud is weighted up to permit deeper drilling, provide a smooth conduit for running in and out of the hole with tools (such as the drill string and bit), and protect the hole from difficult pressure zones. (Conaway, 1999, pp. 149-151)

In order to prevent blowouts (the spewing of oil and gas out of the hole) a blowout preventer (BOP) is installed. A BOP is a safety valve at the top of the hole which include hydraulically operated valves and three sets of rams. The first set of rams can close around the drill string and seal of the annulus, the second one seals of the hole when the drill string is out of the hole, and the last set can cut through the entire drill string and seal of the hole. (Donohue and Lang, 1986, pp. 20-21)

### **3.1.2 Drilling problems**

A number of different problems might occur when drilling a well. The most common problems which might occur are listed below:

- Differential sticking
- Sloughing shale
- Poor mud properties
- Fatigue failures
- Foreign objects
- Poor hole cleaning
- Loss of circulation
- Stuck pipe
  - o Key seating
  - o Packoff from poor hole cleaning

A description of each problem is included in Appendix C.

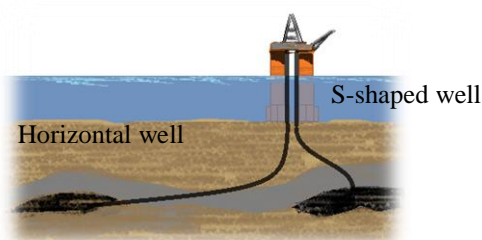
### 3.1.3 History of horizontal drilling

Horizontal wells make an important contribution to the world's oil production and were initially based on an idea of increasing the reservoir-to-well contact. As early as 1919 attempts on drilling horizontally was carried out by drilling horizontal holes from the main vertical borehole. Later on, in the 1940s, specialized drilling equipment with the purpose of drilling horizontal branches from the main vertical well was developed. This specialized equipment included a non-rotating and flexible drilling pipe and turbine. In the years prior 1980, projects utilizing horizontal wells and drain holes were carried out in different countries. These projects showed limited success due to unreliable equipment and high drilling expenditures. (Duan and Farouq, 1995, p. 1).

The major use and technology development in horizontal well technology and well drilling started in the 1980s. At first the wells were short-ranged, with lengths of 250 feet. Technology has since developed further and drilling of far longer horizontal wells is a common practice today (Joshi, 2003, p1). Currently it is possible to drill horizontal wells in the excess of 11 km (Exxon Mobile Corp., 2011).

### 3.1.4 Directional and horizontal drilling

Directional wells usually have an S-shaped profile – the well starts out vertically, then kick off at an angle until the lateral displacement (called reach) is attained, then return to vertical until the reservoir is penetrated (Figure 3.2).



**Figure 3.2. Horizontal well design and S-shaped well design**

Horizontal wells are wells where the hole has been drilled at a very shallow angle or horizontal for some distance within the reservoir (Donohue and Lang, 1986). Statoil defines a horizontal well as a well with a hole section exceeding an inclination of  $85^\circ$  (Blikra, Drevdal and Aarestad, 1994, p. 192). The limitations of the length of horizontal wells are the weight on bit (WOB) applied through gravity, and equivalent circulation density (ECD).

WOB is the amount of weight that is possible to apply to the drill bit – limited by the length and amount of weights used on the vertical section of the hole. “The Equivalent Circulating Density (ECD) is the additional friction pressure loss, i.e. the difference between the annulus well pressure in the start and the end of the horizontal section” (Vestavik, Syse and Aleksandersen, 2010, p. 4). This parameter is important with regards to avoiding kicks and losses, particularly in wells with narrow pressure windows (Schlumberger, 2012a).

A big advantage with horizontal wells is the ability to extend the reach of a platform, and thereby eliminating the need for additional platforms or subsea installations. A horizontal well has a series of disadvantages over horizontal wells as well. A horizontal well has a higher development cost. In the U.S. a horizontal well costs about 150 pct to 250 pct more than a vertical well when both are drilled from the surface. In general, no more than one zone can be produced at a time when using a horizontal well (Joshi, 2003, p. 2).

### **3.1.5 Complex wells**

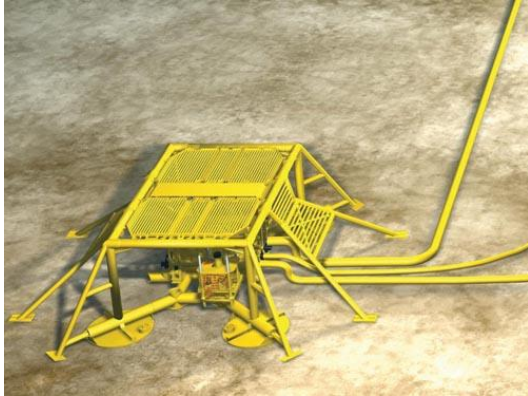
Complex wells are wells which usually fall within one or more of three categories: “High-Pressure, High-Temperature Wells (HPHT wells)”, multilateral wells and depleted zones. HPHT wells are wells with high pressure and/or high temperature conditions. “A multilateral well is a single well with one or more wellbore branches radiating from the main borehole (Bosworth, et al. 1998).” Depleted zones are defined as an isolated section of the reservoir in which the pressure has dropped below that of adjacent zones or the main body of the reservoir section (Schlumberger, 2012b). The case studies in this thesis will not include complex wells, but it is important to be aware of the fact that they exist. The presence of a complex well enhances risk of drilling problems occurring, and special care must be taken when planning and drilling such a well.

### **3.1.6 Subsea Wells**

A subsea well is a well located on the sea floor instead of at a production platform or dry land. A subsea template, also known as a subsea satellite, is the structure placed at the sea floor for supporting the subsea well development and for carrying out oil and gas extraction. (Devold, 2009, p.13)

The wells are drilled, cased and completed through the template from a moveable rig, and the wellhead is placed in a special slot in the template. The slot is connected to outgoing pipelines

from the template (Devold, 2009, p.32). The template itself cannot perform drilling operations. It can only extract and transport the petroleum from the oilfield to an existing platform or a onshore facility through the subsea pipelines. (Devold, 2009, p.13)



**Figure 3.3 Illustration of a subsea template with pipelines and umbilical (Oilinfo, 2010)**

The use of pipeline connections enables a strategically placed production to service many wells over a large area. The use of subsea templates is typically at depths larger than 500 meters. (Devold, 2009, p.13)

From time to time the subsea template wells needs a *well workover*. A well workover refers to different maintenance techniques and operations on the well in order to improve its production capacity. The workover is performed by a mobile rig , typically a remote operated vehicle (ROV). The wellhead structure, which is often called the *Christmas tree*, on the subsea template must allow for this and a series of other operations related to production. (Devold, 2009, p.14)

### 3.2 The Reelwell Drilling Method

The Reelwell Drilling Method is based four key components- the Dual Drill String (DDS), Dual Float Valve (DFV), Flow Control Unit (FCU) and the Top Drive Adapter (TDA) (Reelwell, 2012a, p.2). See Figure 3.4 for an overview of the system.

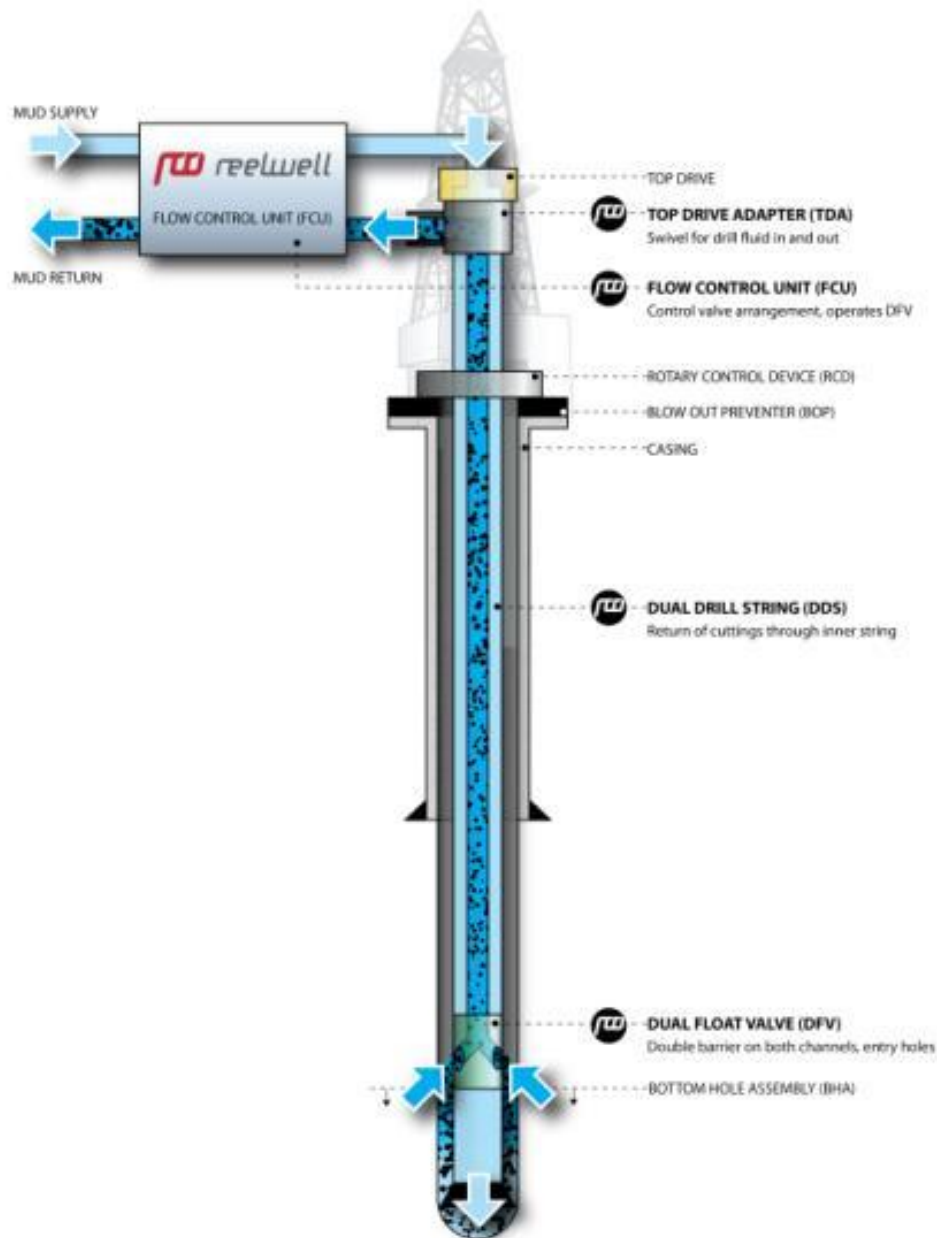


Figure 3.4: RDM system overview. (Illustration: Reelwell)



Dual Drill String (Figure 3.5): The most radical change from conventional drilling is the DDS where the drill string annulus transports the drilling fluid to the bit, and the return flow is transported to the surface through an inner drill string. This creates a closed-loop flow circulation system where the wellbore annulus is free of cuttings. A passive annular fluid is used to equalize the formation pressure.



Figure 3.5 Dual drill string used in a RDM test run in Canada. (Photo: Reelwell)

Dual Float Valve: The DFV enables downhole pressure isolation of the well.

Flow Control Unit: the FCU is a control valve arrangement in which all the active drilling fluid is routed through. The purpose of the FCU is to ensure constant downhole pressure, and a computer is used to measure and monitor the status of the well.

Top Drive Adapter: The TDA is dual conduit swivel that enables the drill string to rotate with the top drive.

An optional component is the Piston (Reelwell, 2012a): The Piston is what allows RDM to potentially drill up to 20 km long horizontal wells. The Piston seals off the section below it, and allows for increased pressure on the section above the piston. This increased pressure functions as a hydraulic weight-on-bit. See Figure 3.6 for a visualisation of the system when the piston is used.

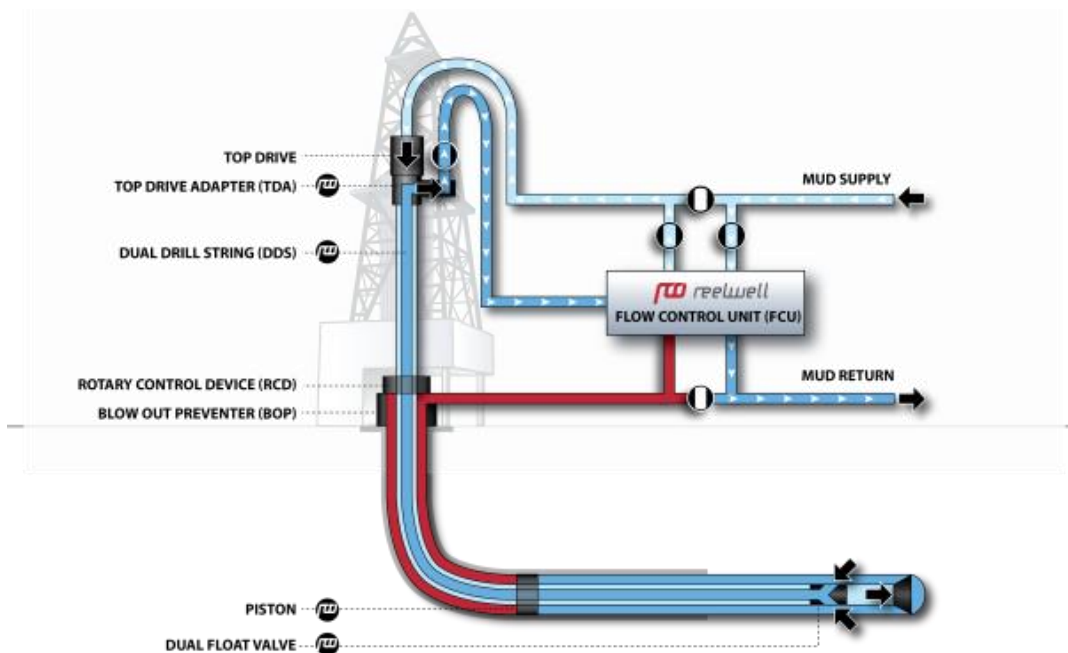


Figure 3.6: RDM system with piston. (Illustration: Reelwell)

The piston is will change the dynamic gradient when drilling long horizontal wells. The ECD in open holes will usually limit the horizontal reach. RDM achieves a static gradient due to the lack of flow in the wellbore annulus. This allows RDM to stay within the narrow pressure window in horizontal wells. See Figure 3.7 for an visualization of the difference in the dynamic gradients for horizontal drilling.



Figure 3.7: ECD, dynamic gradient, (Illustration: Reelwell)

**3.2.1 RDM solutions to drilling problems in long horizontal wells.**

**The Hole Cleaning challenge**

When drilling horizontal wells, cuttings tend to deposit in the lower parts of the horizontal well-hole forming accumulated cuttings beds, as shown in Figure 3.8.

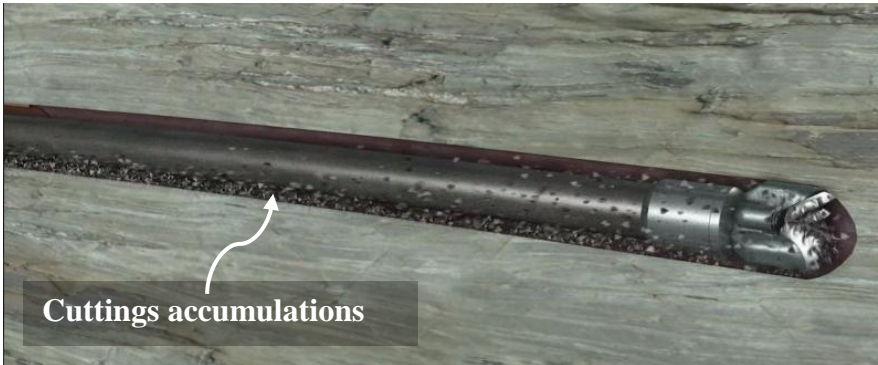


Figure 3.8. In horizontal wells cuttings tend to deposit in the lower half of the wellbore. (Illustration: Reelwell)

Vestavik, Syse and Aleksandersen, (2010, p.4) argue that the RDM solves the hole-cleaning problems in long horizontal wells. The RDM cleans the hole from the bottom, and then transport the cuttings back to the surface trough the inner drill-string (Figure 3.9).

Conventional drilling methods transports the cuttings trough the annulus of the well, but the RDM leaves no cuttings in the annulus. This eliminates the risk of stuck pipes due to cutting accumulations along the horizontal bottom of the wellbore.



**Figure 3.9. Cutting transportation trough the inner drill string using the RDM leaving no cuttings in the horizontal wellbore. (Illustration: Reelwell)**

Good hole cleaning also reduces the *torque and drag*, Torque and drag is produced form friction between the drill string and the well wall, and is particularly apparent in the horizontal and curved sections of the wellbore. Cuttings accumulations along the horizontal bottom of the well path might increase this friction even further (Vestavik, Syse and Aleksandersen, 2010, p.5).

## The ECD challenge

Vestavik, Syse and Aleksandersen, (2010, p.4) defines the ECD as the additional pressure rise necessary for the drilling fluid in the annulus to flow back to the surface. The pressure at the end of the horizontal section, where the drill bit is located, is therefore higher than the pressure at the start of the horizontal section. The pressure loss is due to flow friction along the horizontal section of the well and drill fluid leaking into the formation.

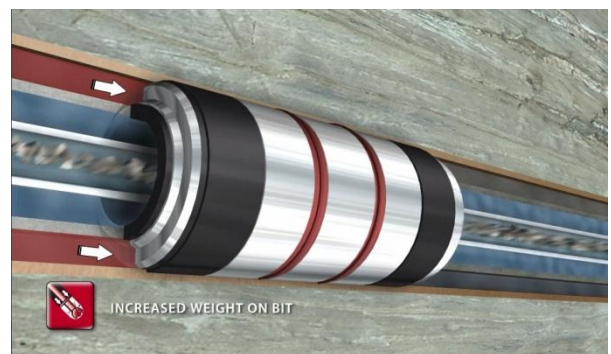
In order to maintain stability in the hole, it is important to keep the pressure within a limited range called the pressure window. According Vestavik, Syse and Aleksandersen, (2010, p.4) this pressure window can be relatively small, possibly in the range of 10 bar. When the dynamic ECD gradient is equal to the pressure window, the maximum length of the horizontal well section is reached (Figure 3.7).

The RDM solves this problem simply by removing the dynamic ECD component because the return flow goes through the inner drill string. The horizontal drilling reach is no longer considered restricted by the ECD, as defined above.

## The WOB challenge

In ERD wells it is a frequent problem to obtain a satisfactory WOB. The problem is particularly noticeable when drilling long horizontal sections in shallow reservoirs because of the short horizontal section. Insufficient WOB force may cause poor penetration rate, and time consuming drilling operations (Vestavik, Syse and Aleksandersen, 2010, p.5).

The RDM resolve the WOB issue by using a sliding piston to push the bit forward. The piston is pressurized from behind, creating an additional hydraulic WOB that works independent of gravity. This creates a significant increase to the total WOB force achievable (Figure 3.10).



**Figure 3.10 Pressurized piston creating additional WOB.**  
(Illustration: Reelwell)

## **Drill String Buckling Problems**

The WOB and down hole frictional forces compress the drill string, and this causes buckling of the drill string. Buckling may occur close up towards the drill bit and all the way back to the neutral point in the horizontal section. Pipe buckling further leads to additional down hole friction, and problems with transferring WOB forces to the drill bit (Vestavik, Syse and Aleksandersen, 2010, p.5).

The RDM equipment layout might reduce pipe buckling the following ways (Vestavik, Syse and Aleksandersen, 2010, p.5):

- If the sliding piston is in the horizontal parts of the well, only the drill string in front of the piston is in compression. Compression and buckling in the vulnerable curved sections of the well can hence be avoided.
- A bigger drill string diameter has greater resistance against buckling. In conventional drilling a slimmer drill string reduces ECD. As described, the RDM eliminates the ECD problem and has the advantage of using a bigger drill string when drilling.

### 3.2.1 Advantages of extended reach drilling with RDM

The longest horizontal section that had been drilled offshore was offshore Russia, and measured 11475 meters and was completed in 2011 by Exxon Neftegas Limited (Exxon Mobile Corp., 2011). If Reelwell can expand the horizontal drilling reach from 11 km to 20 km this will increase the potential drainage area to existing platforms (Figure 3.11). If the horizontal reach increases with 9 km then the total drainage area will increase with 330 pct.

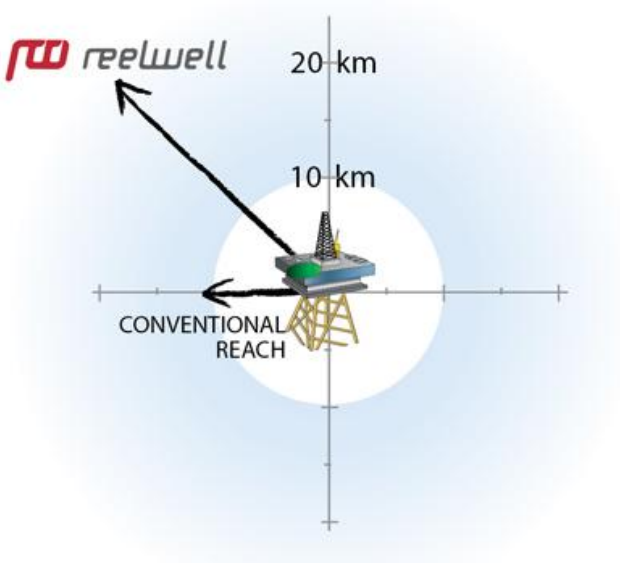


Figure 3.11 – Increased extended drilling reach with RDM (Illustration: Reelwell)

The advantages of being able to drill an extended reach well instead of having to use a subsea well with a tieback to a platform lies mainly in the difference in the rate of recovery between platform wells and subsea wells. The main conclusion is that platform wells have a higher rate of recovery than subsea wells (see chapter 3.3). Other potential advantages are that fewer platforms might be needed to cover a given oil and gas field.

### **3.3 Recovery rates.**

Hill (2010) comments in an article that “A study performed by Statoil, Hydro, and the NPD shows that the recovery factor from subsea wells is 15-20% lower than from wells with direct platform access”. An article from Salthe (2010) confirms this, and states that on a global scale recovery rates from subsea wells are 20 pct and those from direct platform connection are 40 pct. Furthermore, Salthe (2010) explains that the reasons for the big gap in recovery rates are linked to the fact that platform wells can be maintained directly from the platform, whereas in order to perform maintenance on a subsea well an expensive rig must be hired.

The difference in recovery rates is interesting for the case study where an extended reach well is compared to a subsea well. The IOR Expert Committee released a report (Utvinningsutvalget, 2010) which stated that their vision is to increase the recovery rate on oil fields in Norway. According to the committee, the average recovery rate for oil was 46 pct on Norwegian oil fields. An increase of one percent point in the average recovery rate would increase the gross value potential by NOK 246 billion according to the committee’s calculations.

### **3.4 Validation of data**

This chapter is for information only, and will give a short introduction on how to validate the data used in the model.

When costs are included in a theoretical case study, the costs need some sort of validation in the form of data. The data can come from simulations or benchmarking. Benchmarking well costs are usually done with the support of a database called “Rushmore Reviews”. Rushmore Reviews is a company which provides drilling and completion data to those who participates in their program. To participate in their program one need to pay a fee and “must provide 100% of the required data on 100% of the wells drilled in any country of participation” (Rushmore Reviews, 2012). Access to Rushmore Reviews is restricted to the participants of Rushmore Reviews’ program.

By using the database in Rushmore Reviews one can easily make scatter plots of all the wells which contain the same parameters as your planned well. The scatter plots can then be used to show the different quartiles. These quartiles will be used in an estimation of the time and cost of the planned well.

Reelwell does not have access to Rushmore Reviews at this date. If the model is to be applied on a real-life case study, then a participant in Rushmore Reviews would be approached and asked to verify the data and assumptions used.

As applying the model on a real-life case is outside the scope of this thesis, verification though Rushmore Reviews has not been done.



### **3.5 Well cost estimation model**

Well costs are estimated using a model. Each company usually has their own custom models which are made according to their business plan. In this thesis we will use a generic cost estimation model based on the different models which the oil companies usually use (Anon, 2012). The model will be presented below:

The five step model for well cost estimation.

- 1) Business plan, initiation report and feasibility study.
- 2) Select a concept – economic analysis and well specification.
- 3) Approval – Go/No go, AFE (Approved for Expenditure) estimation.
- 4) Pre-drilling (pre-spud) estimation, the project is executed.
- 5) EOW (End of Well) Report.

Step 1: The initiation stage of the project. A business plan has to be made, an initiation report presented and a feasibility study must be executed. This thesis assumes that this stage has already been done, and that the different cases which are presented later in the thesis are feasible.

Step 2: Different concepts are explored and analyzed, and a single concept is chosen. Each concept needs an economic analysis and well specification. At the end of this stage a concept will be chosen and forwarded to Step 3. We assume that we are at the point where different concepts are described and analyzed in this thesis.

Step 3: A decision has to be made whether or not the concept chosen in Step 2 gets to continue or not. If go, then an AEF has to be made. At this point a detailed well design and execution plan is made.

Step 4: A pre-spud estimation is made, and the project is executed. During the execution it is important so monitor and control the cost expenditures, and check how they match the estimations.

Step 5: An EOW Report is made. At this point all the actual costs involved in the project are known, and an evaluation of the well cost estimations has to be done.

To summarize: The basic assumption of this thesis is that we are somewhere in step 2. This assumes that the concepts are feasible, and that the cases which will be presented later will focus on the economic analysis and well specifications.

**3.6 Determining which cost factors to include when estimating well costs.**

When deciding which cost inducing factors to include there is a balance which must be struck between too many details and too few details. At the high level estimate one could group the cost elements as: Rig, subsurface services, fluids, wellhead equipment and services, and logistics. Each element can further be broken down into sub-elements. E.g. subsurface services can be broken down to directional drilling services, wireline logging, mudlogging and fishing, milling and P&A services.

The basic list of the elements which are usually present during an offshore well project drilled from a platform (Reelwell, 2012a):

|  |
|--|
| <i>Rig</i>   |
| <i>Rig costs (all included)</i>                        |
| <i>Subsurface services (grouped)</i>                   |
| <i>Directional Drilling Services</i>                   |
| <i>Wireline Logging (open and cased hole)</i>          |
| <i>Mudlogging</i>                                      |
| <i>Fishing, Milling and P&amp;A Services</i>           |
| <i>Fluids (grouped)</i>                                |
| <i>Cementing Services</i>                              |
| <i>Drilling Fluids &amp; Mud Engineering</i>           |
| <i>Drilling Waste Management</i>                       |
| <i>Other Major Services</i>                            |
| <i>Wellhead Equipment &amp; Services</i>               |
| <i>Casing and Tubular Running Services</i>             |
| <i>Casing</i>  |
| <i>Tubulars (Conventional/RDM)</i>                     |
| <i>ROV</i>   |
| <i>Logistics</i>                                       |
| <i>Helicopter</i>                                      |
| <i>Standby Vessel</i>                                  |
| <i>Supply Vessel</i>                                   |
| <i>Anchor Handling Vessels / Pre-laying of Anchors</i> |
| <i>Logistics (base)</i>                                |

**Table 4: Cost-elements in offshore well (Reelwell, 2012a)**

The list does not include the cost elements which are specific to subsea installations. In the case of subsea installations the following cost elements would be included (Reelwell, 2012b):

---

*Subsea production system*

---

*X-mas tree*

*Control systems*

*Installation*

*Flowlines and umbilical*

**Table 5: Cost elements in subsea (Reelwell, 2012b)**

Depending on the case, the level of detail of the list of cost elements will vary. Model CC where RDM is compared to the conventional drilling method will require a high level of detail. This is because the purpose of the case is to highlight the advantages RDM have over conventional technology when drilling the same well. Model FDA where one compares drilling a long horizontal well to reach a reservoir compared to a subsea installation demand a less detailed breakdown of the cost elements. In this model the purpose is to see how the net present value change depending on which solution is chosen. This requires a thorough economic analysis combined with a technical evaluation. A high level of detail in the cost estimation is not needed because individual cost break-down is not in itself interesting, the potentially increased NPV is the focus.

Our list of cost elements and cost-breakdown elements was developed with input from Reelwell, and the final list reflects the elements which is a typical breakdown in the oil and gas industry.

Each element or sub-element will be estimated by a fixed cost, a variable cost, or a combination of these. Fixed costs are costs that are independent of time. Examples are the costs of mobilization fee and depth dependent costs. The length or depth of the well is known, the depth dependent cost can be modeled as a fixed cost. Variable costs are all costs which are time-dependent. Examples of time dependent costs are logging and helicopter services.

RDM will affect both the fixed and variable costs of certain elements. In a field development case we will assume that the given oil company is aware of the effects RDM have, and have included it in their cost estimations.

The cost-elements will not be discussed as they may vary from company to company. The list is an example of the cost-elements that Reelwell use, and the model reflects this. If other companies want different cost-elements, then the model would have to be changed accordingly.

### 3.7 P10, P50 and P90

#### Defining P10, P50 and P90

The P10, P50 and P90 confidence levels are the same as the 10 pct, 50 pct and 90 pct cumulative frequency (Cooper Energy, 2010). In other words, P50 is the value which the estimates are expected to exceed 50 pct of the time (likewise with P10 and P90). P50 does *not* mean that the given value will occur 50 pct of the time.

#### Probabilistic Methods for reserves estimation

The total petroleum recovered is a product of *rate of recovery* and *reservoir size* (Figure 3.12). According to SPE (2001, p.41) both these factors have an inherit uncertainty which can be described as a *probability density function* (PDF). Probabilistic methods are commonly used as an estimation tool in order to describe the uncertainty range of remaining reserves and recovery rate (Gupta S., Gupta R., Elk and Vijayan, 2010, p.1). In order to obtain the distribution of the total petroleum recovered Monte Carlo simulations can be used. Once the sample space (all possible combinations of rate of recovery times reservoir size) is defined then a large (>1000) number of random combinations are chosen. The random samples are then arranged in a histogram, and a best fit of a continuous distribution is calculated in order to obtain the distribution of the total petroleum recovered.

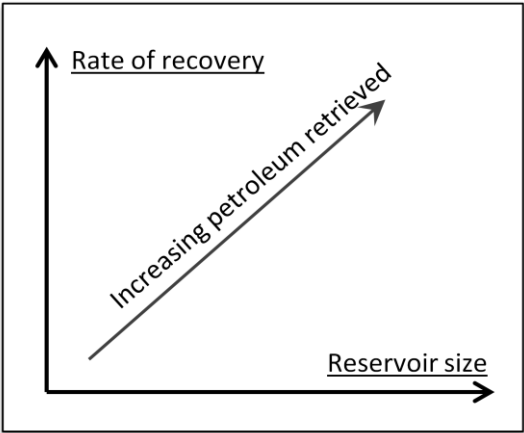


Figure 3.12: Sample space

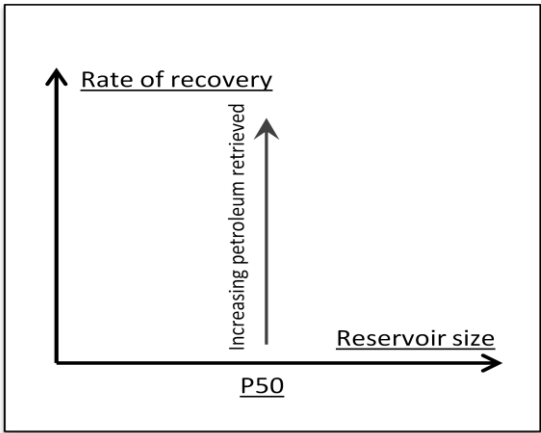


Figure 3.13: Fixed reservoir size

## P10, P50 and P90

SPE (2001) gives guidelines for a three leveled percentile evaluation model for reporting the dispersion in estimated total retainable reserves. The three levels are (with alternative names):

- *P90, Proved*
- *P50, Proved + Possible*
- *P10, Proved + Possible + Probable*

By this definition there is a 90% chance, or confidence, that the actual recovered reserves exceeds the estimates given in the P90 case. The P50 and P10 are defined in the same way where the confidence levels are 50% and 10% respectively. P50 is also known as the median value.

To actually calculate the percentiles in retainable reserves is beyond the scope of this thesis. Model FDA is simplified by not defining any uncertainty related to the reservoir volume, and the reservoir size can then preferably be set to the median value (P50) as shown in Figure 3.11 and Figure 3.13. Hence the recovery percent is the only contributor to the total reserves retained.

However, multiple FDA-models can be set up with different percentiles for reservoir size, e.g. P10, P50 and P90 reservoir size as shown in Figure 3.14, giving a sample space matrix for the different value cases.

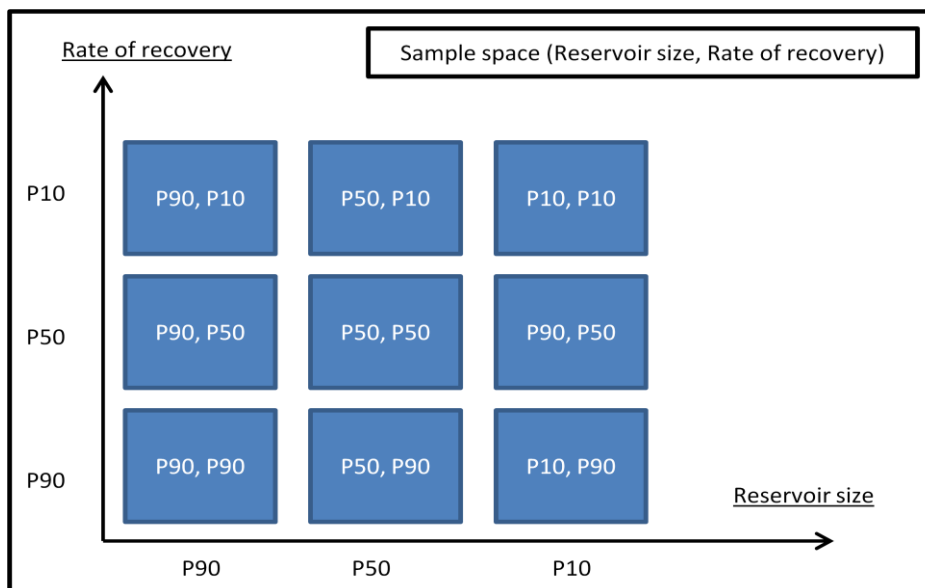


Figure 3.14: Sample space matrix

## 4. Theory – Economics

### 4.1 Capital budgeting techniques.

Decision criteria are necessary when using a model to evaluate two possible solutions. The decision criteria include capital budgeting techniques, company policies and other stakeholder opinions. Capital budgeting techniques are methods which evaluate whether or not an investment is profitable. Company policies and other stakeholder opinions are other factors which must be taken into account when evaluating whether an investment is profitable or not. Examples include focus on using new and greener technology – even though the initial investment might be higher. The objective of the model includes modeling parameters which can support decision making with regards investments. Because the model can only take quantifiable parameters into consideration, the model is limited to focus on capital budgeting techniques. The next two sub-chapters will explain the use of Net Present Value (NPV) and Internal Rate of Return (IRR).

#### 4.1.1 Estimating Net Present Values.

Net Present Value (NPV) will be calculated in the model in order to evaluate the extended reach well compared to the subsea installation. NPV is defined as the sum of future discounted cash flows less the initial investment, and if the NPV is greater than zero, then the investment is profitable (Hoff, 2010, p 394).

A typical NPV formula is as follows Hoff, 2010, p 394):

$$NPV = -I_0 + \sum_{t=1}^n \frac{C_t}{(1+r)^t}$$

Where  $I_0$  is the initial investment at year 0,  $C_t$  is the cash flow in year  $t$  and  $r$  is the discount rate the company chooses to use. In this model  $C_t$  will be the post-tax cash flow in year  $t$ . The discount rate can be found by using the after-tax Weighted Average Cost of Capital (WACC) (Brealey, Myers and Allen, 2008, p 488). In other words  $r = \text{after-tax WACC}$  when  $r$  is assumed to be the expected rate of return of the companies projects.

WACC is the overall required return on the firm's outstanding securities, and reflects the average risk of the firm's projects. In other words the WACC can be used as a hurdle rate –

“the minimum acceptable rate of return on a project” (Brealey, Myers and Allen, 2008, p 490, G-6 and G-14). After-tax WACC is defined as (Brealey, Myers and Allen, 2008, p 488):

$$WACC = \frac{E}{V} \cdot R_e + \frac{D}{V} \cdot R_d \cdot (1 - T_c),$$

Where  $E$  is market value of the firm’s equity.  $D$  is the market value of the firm’s debt.  $V = E + D$ .  $R_e$  is cost of equity, and  $r_d$  is cost of debt.  $T_c$  is corporate tax rate.  $\frac{E}{V}$  is the percentage of financing that is equity, and  $\frac{D}{V}$  is likewise the percentage of financing that is debt.

$R_e$  can be calculated by using Capital Asset Pricing Model (CAPM) which described the relationship between risk and expected return (Brealey, Myers and Allen, 2008, p 214):

$$R_e = r_f + \beta (r_m - r_f),$$

Where  $r_f$  is the risk free rate and  $r_m$  is the expected market return.  $\beta$  is the risk measure that compares the returns of the asset to the market over a period of time and to the market premium ( $r_m - r_f$ ).

$R_d$  is the effective rate that a company pays on its current debts. This rate is equal to  $r_f$  plus a risk premium that reflects cost and risk to the creditors.

The formulas above show how it is possible to calculate a discount rate which is based on average risk a firm is willing to take on its projects. The discount rate  $r$  is however, defined by the user who might not necessarily define  $r = WACC$ .

#### **4.1.2 Estimating Internal Rates of Return.**

The internal rate of return (IRR) is defined as the discount rate ( $r$  from chapter 4.1.1) which gives a NPV equal to zero. The IRR is a different way of looking at the NPV; if IRR is greater than the minimum acceptable rate of return or cost of capital, then the project is profitable (Hoff, 2010, p 397). IRR is usually calculated by using software (e.g. Excel) because the calculations involve iteration and can be time consuming.

According to Bierman (2012, p 1) the IRR will lead to the same results as the NPV as long as the investments considered are independent. If the projects are mutually exclusive, then the NPV is more reliable and accurate than the IRR. In the case of mutually exclusive investments only one investment will be approved. In this case, the investment with the

highest IRR might not necessarily have the highest NPV. E.g. investment A has an IRR of 10 pct. and an NPV of USD 50 million, while investment B has an IRR of 5 pct and an NPV of USD 100 million. According to IRR, investment A should be chosen, but investment B clearly earns the company more money.

IRR is popular because it can be used to show the difference between the required rate of return and the investment's IRR. This is a measure of safety which can be used to evaluate the risk of the investment compared to investment's return. The NPV does not give this measure of risk (Bierman, 2012, p 3). It should be noted that the NPV does take into account the minimum acceptable rate of return when calculating  $r$  (see chapter 4.1.1).

Model FDA has to compare two investments which will be treated as mutually exclusive – an extended reach well (RDM) versus a subsea installation. IRR will be included as a output when showing the results of this comparison due to its popularity in among managers, and as a measure of risk.

#### **4.1.3 Calculating the NPV and IRR in the excel model**

The excel model has to be able to account for an important feature of production – decreasing unit costs. When production increases, then unit costs might go down. In order to model the value of this feature a “trick” was employed. First a cash flow is established for the case that no investment is made – we call this a *base-line* cash flow. Then a cash flow is calculated for RDM and SubSea using the total production (base-line + added and lost production from RDM or SubSea), and the NPV and IRR is calculated based on the difference between the cash flows for RDM and SubSea and the base-line.



## 4.2 The taxation of petroleum activities.

In order to obtain a post-tax cash flow for the NPV-analysis, the model must be able to calculate the tax level which is levied at the projects. This chapter will attempt to give an overview of the Norwegian tax system with respect to petroleum activities.

Oil and gas companies are subject to the regular company tax (28 pct) and a special tax (50 pct) (Ministry of Finance, 2012). The total tax levied upon all oil and gas companies is 78 pct. There are two important factors which reduces the marginal tax rate: Depreciation and uplift

Depreciation: The acquisition of production facilities and pipelines may be subjected to a linear depreciation schedule of up to six years (up to 16 2/3 pct. annually) as from the year the investment was made.

Uplift: Uplift is an additional depreciation on the production facilities and pipelines which may be depreciated linearly over six years. The uplift has been 7,5 pct since 2005, and can be used for 4 years, where the first year is the year the investment was made.

The calculation of tax can roughly be set up in the following manner (Ministry of Finance, 2012):

*Sales income (calculated by norm prices)*

- *Operating costs (inclusive of exploration costs and indirect taxes)*
- *Depreciation (calculated by rules particular to the petroleum sector)*
- *Net financial costs (based on the ratio between the tax value of operating assets on the shelf and the average interest-bearing debt over the tax year)*
- *Losses carried forward from previous years*

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*= Ordinary tax base at 28 pct.*

- *Uplift (investment-based “supplementary depreciation”)*
- *Unused uplift carried forward from previous years*

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*= Special tax base taxed at 50 pct.*

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**Table 6: Taxation of petroleum activities in Norway (Ministry of Finance, 2012)**

The norm price system: For tax purposes the price which petroleum is sold is calculated according to the norm price. The norm price is the price which petroleum could have been traded between independent parties in an open market. This is due to the widespread integration between purchasers and sellers, and the hard task authorities would have at

determining whether or not the oil prices are fair (Skatteetaten, 2010). Norm prices have only been determined for crude oil (Ministry of Finance, 2012).

The post-tax cash flow will be used in the model to calculate the NPV (se chapter 4.1.1).

In the case that a non-Norwegian tax system is used, an effective tax rate will be used in the model. It is outside the scope of this thesis to accurately describe the taxation system of all the different countries which might use RDM. The effective tax-rate is a useful approximation as it is easy to apply a flat tax-rate in Model FDA, but difficult to accurately model other tax systems than the Norwegian tax system.

### **4.3 How to model oil and gas prices.**

When a project in the oil and gas industry is evaluated, the oil and gas prices are important decision criteria with regard to calculating the NPV (and other capital budgeting criteria). Modeling the behavior of oil and gas prices is very complicated. Many factors have an impact on a price-model, of which some are mentioned below:

- Correlation between oil prices and costs in the valuation of the project. Price and cost tend to co-move because increased cost puts pressure on prices, and high oil prices increases demand for constrained resources such as oil rigs, specialized personnel, etc. This correlation has an impact on the NPV valuation, and the absence of this correlation may lead to errors of up to 25% under real option valuation (Costa Lima, Schiozer and Suslick, 2008, p 60).
- Oil and gas prices are subject to unsystematic risk with regards to political and economic events in the world at large. Wars involving oil producing countries have a tendency to give rise to high oil prices (Williams, 2011) (Figure 4.1). Unsystematic risk is hard to quantify, and is easiest described using scenarios.

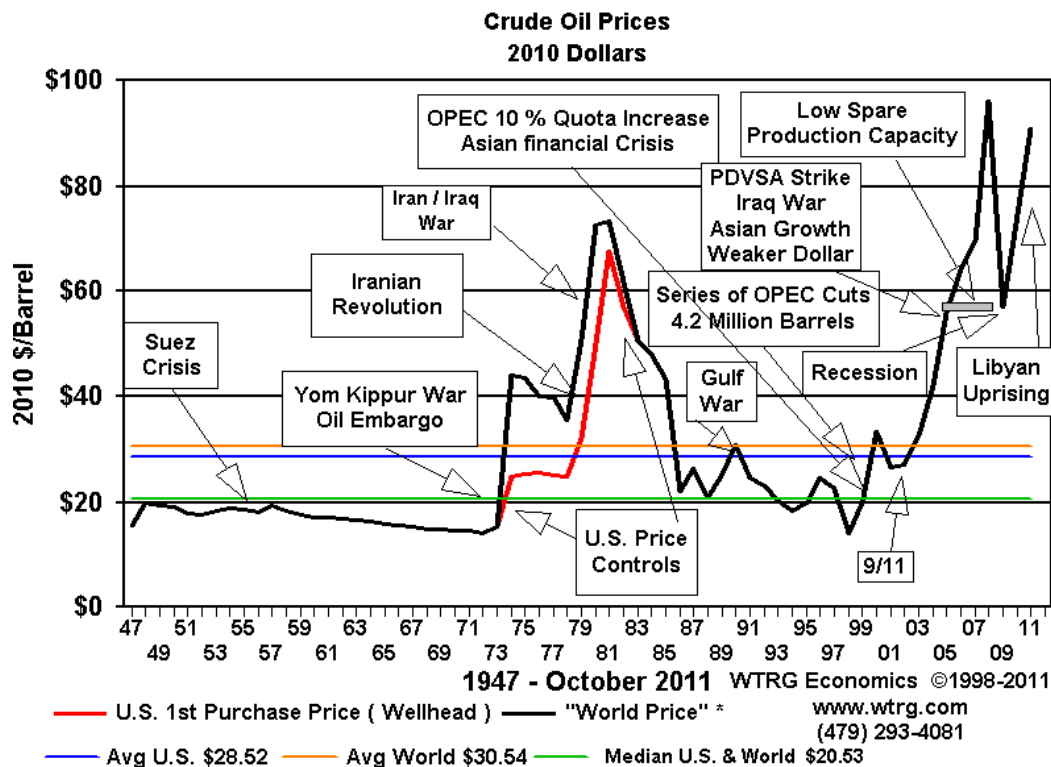


Figure 4.1: Crude Oil Prices (WTRG, 2011)

This thesis will not attempt to model the oil and gas prices in a quantitative manner. Modeling oil and gas prices accurately is outside the scope of this thesis, and is not necessary as such for the purpose of the model.

Model FDA has two options for modeling oil and gas price levels. Option one is to model the price levels as static. The assumption is that the minimum return rate at that price level is an expression of the investor’s risk aversion. In other words the combination of price level and the minimum return rate at that price level expresses how much risk the investor is willing to commit to. Option two is to make a forecast of the oil and gas price for the years in which the investment is active. There are no tools in the model which supports such a forecast – the user must acquire the forecast from other models.

## **4.4 Alternative solutions to the model**

This chapter is included in order to highlight two alternative approaches to making the model for Reelwell. The first two sub-chapters will explain briefly what econometrics and the generalized functional model are, respectively. The third sub-chapter will explain why these alternate solutions were not chosen.

### **4.4.1 Econometrics**

Econometrics is the field of economics that concerns itself with the application of mathematical statistics and the tools of statistical inference to the empirical measurement of relationships postulated by economic theory (Greene, 2003).

### **4.4.2 The generalized functional model**

The generalized functional model is a general framework which seeks to identify the relevant characteristics of drilling operations and show how these characteristics can be quantified in order to estimate the drilling costs (Kaiser and Pulsipher, 2007). The characteristics (factors) account for all the variables which can influence the total drilling cost such as drilling characteristics, well characteristics and formation evaluation. The downside to the generalized functional model is that it is complex and needs a large amount of data in order to be effective.

### **4.4.3 Exclusion of the alternate solutions**

Ideally this thesis would have used a combination of econometrics and a generalized functional model for cost estimation. This approach demands a number of comparable wells where conventional drilling equipment and the RDM have been used. The data from the wells would have been used to establish empirical relationships between the factors which are used to describe the cost estimate (Kaiser and Pulsipher, 2007). Once the relationship between the factors has been defined, econometrics would be used to check how the oil price and the economic situation would affect the model.

Unfortunately, Reelwell's product has not been used in enough wells yet that this approach is viable. Furthermore, this approach requires more time than the four and a half months that this thesis had available.

## 5. Excel

The model in this thesis was developed with Excel 2007. Excel 2007 is a spreadsheet application developed by Microsoft as part of their office suite Microsoft Office for the MAC OS X and Microsoft Windows operating systems. According to Mick (2010) Microsoft Office have had a steady 94 pct. market in 2010 and 500 million customers worldwide. Rigby and Oreskovic (2010) state that 81 pct of the companies in 2010 used Microsoft Office. The scope of this thesis specifies that the model is to be developed in Excel. This is due to the fact that the model should be accessible to as many potential customers as possible for Reelwell. Further information on the specific features of Excel 2007 can be found on Microsoft's homepage.



Figure 5.1 – Excel 2010 logo (Microsoft Office (2012))

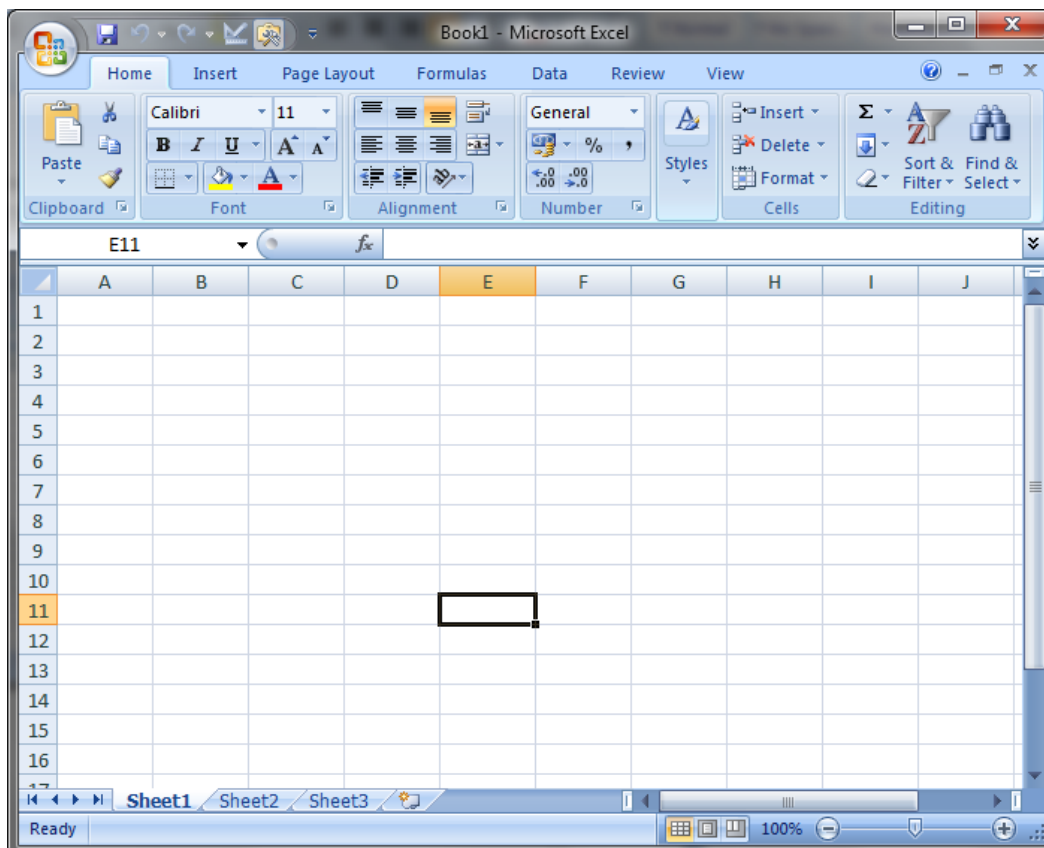


Figure 5.2 – Print Screen form a blank Excel spreadsheet.

## 6. The value case model in Excel

The value case model had to be able to handle two types of cases according to the initial scope: Cost comparison (CC) of a direct comparison between using RDM and conventional drilling equipment on the same well, and a field development analysis (FDA) where RDM is used to drill horizontally from a platform versus a subsea installation. This was accomplished by developing two models in Excel. Later the scope was redefined to that the value case model should be able to compare any two drilling programs and any two field development investment options.

This chapter is divided in three sub-chapters. Chapter 6.1 gives a brief introduction to the structure of the model in order to give a foundation for the next chapters. Chapter 6.2 contains chapter 6.2.1 and 6.2.2 which explain in detail model CC and model FDA respectively. Chapter 6.3 details the seven development cycles mentioned in chapter 2.

The documentation of the model needs by necessity screenshots of the Excel models. In order to make the screenshots easier to understand, the first screenshot of a spreadsheet will always be of the entire spreadsheet. The second screenshot will be a copy of the first, but with explanations of which main components are present. The remaining screenshots of the given spreadsheet will be used to highlight areas of interest. See Figures D1.1a and D1.1b in Appendix D for an example.

For ease of reading a spreadsheet will hereafter be referred to as a *sheet*. Most of the screenshots are too large to be included in the text, and have been put in Appendix D. These screenshots have the prefix D, i.e. *D1.1*.

Enclosed with the physical copy of this thesis is a CD-ROM containing the Excel-file with the value case model. Likewise does the CD-Rom copy delivered to UiS contain the Excel-file. The reader is recommended to browse the Excel-file in order to actually see how the model functions.

### 6.1 An introduction to the model

A brief introduction to the model’s functional structure (see Figure 6.1) follows below. Note that this description explains the principles of the model, and does not describe the sheets which only contain information (such as the *Main Menu*, *FAQ*, *Instructions: CC* and *Instructions: FDA*).

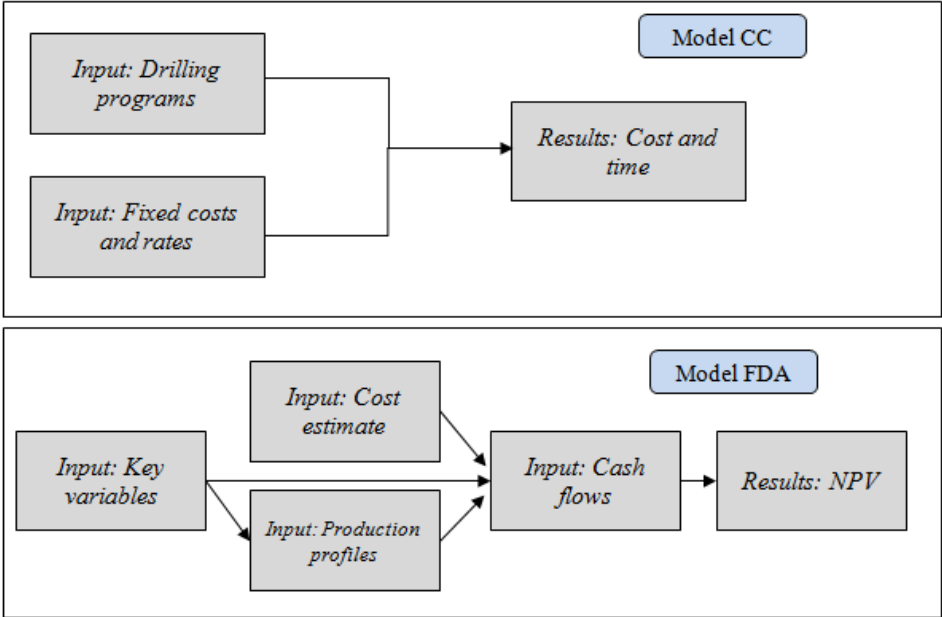


Figure 6.1. Showing the functional structure of the value case model

**Model CC:** The functional structure consists of three sheets – two sheets for input and one for results. The two input sheets are *Input: Drilling programs* and *Input: Fixed costs and rates*. The *Input: Drilling programs* is a sheet where the user can enter two different drilling programs for the same well. See Figure 6.7a (page 39) for an example of a drilling program. The *Input: Fixed costs and rates* is a sheet where the fixed costs and rates related to the drilling programs are entered. *Results: Cost and Time* shows a comparison of the costs and time usage related to the two drilling programs.

**Model FDA:** The functional structure consists of five sheets – four for input and one for the results.

The first input sheet is called *Input: Key variables* and is used to enter discount rates, tax rates, oil and gas prices and choose a system of measurement (US customary units or metric). The discount rates are used in the *Results: NPV* sheet in order to calculate the NPVs. The tax

rate and oil and gas prices are used in the *Input: Cash flow* sheet in order to calculate a post-tax cash flow. Lastly the system of measurement affects which unit is used when entering data in the *Input: Production Profiles* sheet.

The second sheet *Input: Cost estimate* is used to define the cost of the two investment options (in this case an extended reach well and a subsea installation). The investment cost needs to be manually entered in the *Input: Cash flow* sheet at the year which the investment is made. The reason for this is explained in chapter 6.2.3.

The third sheet is *Input: Production Profiles*. This sheet is used to enter the P10, P50 and P90 production profiles. For each profile (P10, P50 or P90) a base profile for the entire field and the added or lost production for RDM or SubSea needs to be defined. The production figures are used to calculate the gross revenue per year of production in the *Input: Cash flows* sheet.

The fourth sheet is *Input: Cash flows*. This sheet is used to calculate the post-tax cash flows which are later used in the sheet *Results: NPV* in order to calculate and compare the NPV of each investment option. A cash flow is needed for each investment option in P10, P50 and P90 (corresponding to the three production profiles). Each cash flow needs to include the operation costs, the transport costs, other costs (if any) and the investment costs.

The fifth sheet is *Results: NPV* which shows a comparison of the NPVs and IRRs, a graph of the expected production and a graph of the present values of the cash flows. A matrix also shows how much production of oil or gas each investment option adds to the total production of the field.



## 6.2 Describing the final models

This chapter will explain the model extensively and give a thorough overview of how the model is intended to be used. Due to the size of the screenshots of the model, most of the screenshots are included in Appendix D. The reader is recommended to look at the screenshots in order to gain a deeper understanding of the model. Unless otherwise noted, all pages have a print button on them.

### 6.2.1 Main Menu, FAQ and Toolbars

The *Main Menu* is the main sheet of the model (Figure D1.1a), and contains a number of important elements that together give the user an overview of the two models and the features available. The elements are (Figure D1.1b): A flowchart showing the two models, a legend describing the flowchart, a button to the *FAQ*, a logo giving access to Reelwell and a disclaimer and copyright.

The *Flowchart* shows all the sheets involved in two models, and the names of each sheet in the flowchart are hyperlinks to their respective sheets (Figure D1.1c). This allows the user to access on any given sheet in the model via the *Flowchart*.

The *FAQ* is accessed through the button on *Main Menu* and hyperlinks links on other sheets where applicable. The *FAQ* includes only information in common problems that might occur and other issues that the user needs to be aware of. Details in the *FAQ* will be given when the appropriate sheets are explained. The *FAQ* includes a button allowing access back to the Main Menu, a button for searching the *FAQ* and a list of questions and answers (Figure D1.2).

All sheets except the *Main Menu* and *FAQ* have a toolbar on the top of the page. These toolbars show all the relevant sheets in the given model, and is used to quickly navigate the model (Figure 6.4 and Figure 6.5).

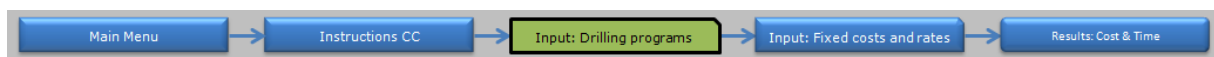


Figure 6.2. The toolbar for model CC. Each of the blue boxes is a direct link to the given sheet. Activated sheets are shown as green, e.g. *Input: Drilling programs*.

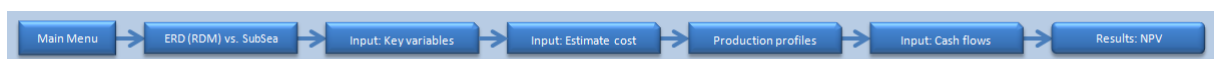


Figure 6.3. The toolbar for model FDA. Each of the blue boxes is a direct link to the given sheet.

## 6.2.2 Model CC – Comparing RDM with conventional equipment

Model CC consists of four sheets: *Instructions CC*, *Input: Drilling programs*, *Input: Fixed costs and rates* and *Results: Cost & Time*.

### *Instructions CC*

*Instructions CC* is the first sheet in model CC. This sheet explains what this model's case study is (comparing RDM to conventional equipment), which assumptions that are made and which steps the user need to complete in order to get the cost analysis in *Results: Cost & Time* (Figure D2.1a and Figure D2.1b). There is also an option button which allows the user to choose their preferred system of measurement – metric system or US customary units.

### *Input: Drilling programs*

*Input: Drilling programs* is the second sheet and is used to enter two drilling programs (see Figure 6.7a. Figure 6.7b shows the three main components in the sheet: The input section for the drilling programs, a simple risk analysis with respect to time and a graph showing time versus depth.

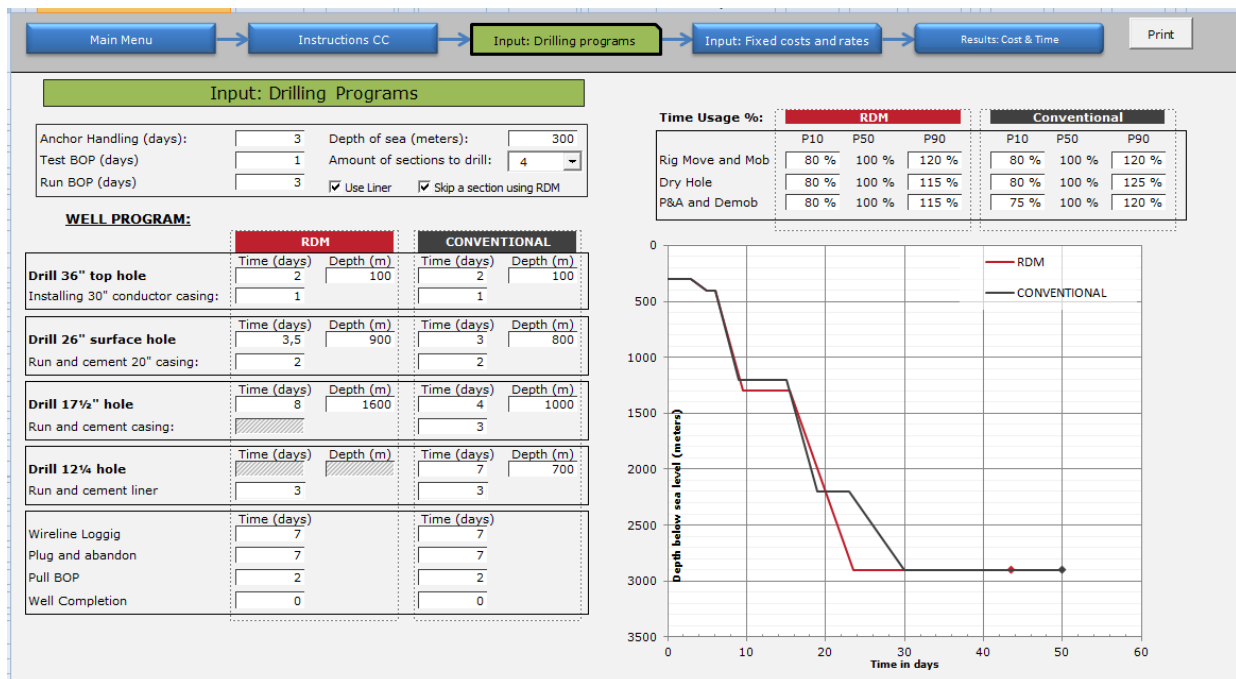


Figure 6.4a - Sheet *Input: Drilling Programs*

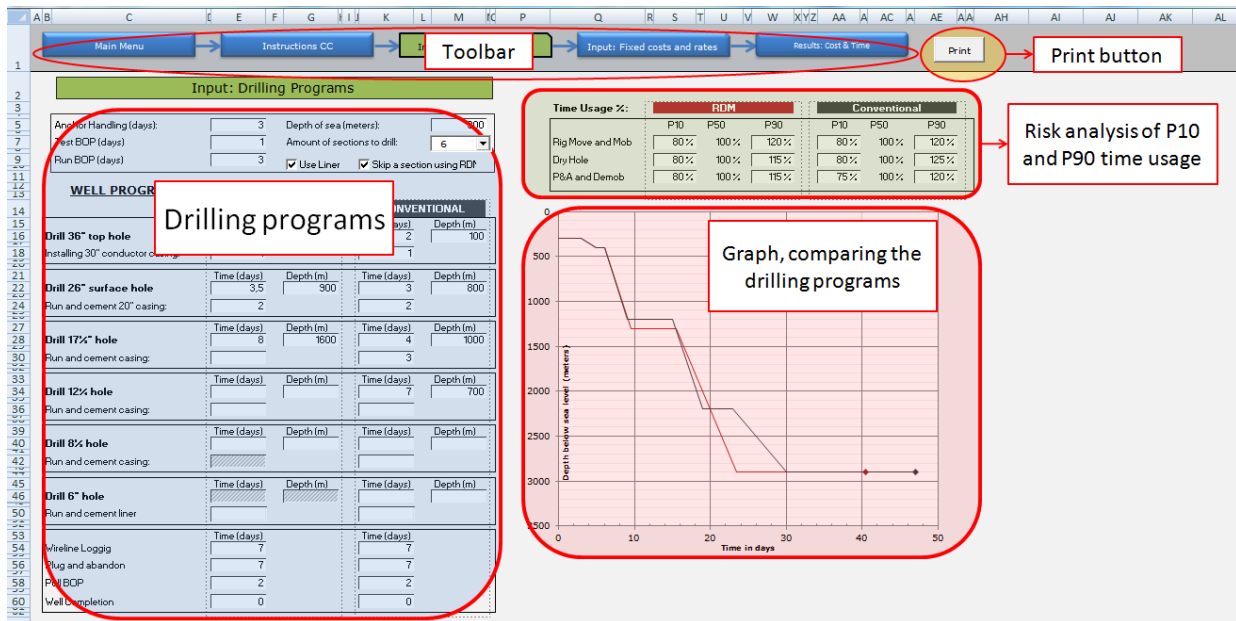


Figure 6.4b - Sheet *Input: Drilling Programs*

The drilling program input section allows the user to specify how many sections that will be drilled, if a liner is being used and if one of the drilling methods uses one less casing. RDM might have the potential to save a casing, and this feature is implemented in the model.

The risk analysis allows the user specify P10 and P90 as a percentage of P50. In other words P50 is defined as 100 pct and P10 and P90 are defined relative P50. E.g. P50 is 100 hours, P10 is 120 pct (120 hours) and P90 is 80 pct (80 hours). This feature is a way of showing the sensitivity of the drilling programs with respect to time.

The graph is a visual representation of the time and depths in the drilling programs. The graph serves as a way to ensure that the data which is entered in the drilling programs make sense. If the graph looks wrong, some data may have been entered wrongly.

### ***Input: Fixed costs and rates***

*Input: Fixed costs and rates* is the third sheet, and is used to enter the fixed costs and rates (time and depth) and combine them (Figure D2.2a). The main components in this sheet are (Figure D2.2b): the input section for the fixed costs and rates, the key times and depths (from *Input: Drilling programs*), total costs of P50 and set of buttons for showing/hiding the total costs of P10 and P90.

The input section for the fixed costs and rates is used to enter the estimated cost-elements related to each drilling program. The user is free to model the cost-elements in any way desirable. Costs may be fixed, rate/day, rate/meter (or feet) or a combination of the three. A list of the cost element is given in chapter 3.6.

The key times and depths section is a matrix with values extracted from *Input: Drilling programs*. These key figures are used together with the fixed costs and rates to calculate the total costs. At the bottom of the matrix the user has the possibility of adding a user-defined value.

If the buttons for showing the total costs to P10 and P90 are activated the columns hiding the total costs are revealed (Figure D2.2c). Figure D2.2d shows the main elements when P10 and P90 are revealed: Tables with the total costs of P10, P50 and P90 and the time usage in pct to P10 and P90. The total cost sections are where the user combines the fixed costs and rates with the key times and depths in order to arrive at the total costs for each drilling program. The time usages in pct are used to define the P10 and P90 time estimates. The user must manually multiply the percentages with the relevant time-dependent costs from the P50 total costs table.

### ***Results: Cost & time***

The final sheet is Results: Cost & Time (Figure D2.3a). The purpose of this sheet is to show the cost difference between the two drilling programs in question. The sheet consists of three main components (Figure D2.3b): A cost comparison table, buttons and a graph.

The cost comparison table shows the cost-elements from the sheet *Input: Fixed costs and rates*, and show the difference between the two drilling programs (Figure D2.3a). Figure D2.3d shows P50 and its cost-breakdown structure.

The configurations of the table are controlled by the buttons (Figure D2.3b). Depending on which buttons are active, the table is configured accordingly. The table shows initially the main cost-elements and the P50 estimate of the costs (Figure D2.3a), but can be expanded to show the cost breakdown and/or the P10 and P90 cost estimates. Figure D2.3c shows P10, P50 and P90, but with the cost breakdown collapsed. Figure D2.3e shows P10, P50 and P90 with their corresponding cost-breakdown.

The graph is used to highlight the spread between P10, P50 and P90, and thus serve as a basic risk analysis with respect to the influence the uncertainty around the time-usage in the drilling programs have on the total cost.

**6.2.3 Model FDA – Comparing an ER well (RDM) with a subsea installation**

Model FDA consists of 6 sheets: *Instructions FDA, Input: Key Variables, Input: Estimate cost, Input: Production profiles, Input: Cash flows, Results: NPV and ProdGraph.*

This model assumes that “no investment” is the option where nothing is done because it is not possible to reach the outlying reservoir with conventional technology (Figure 6.8). An extended reach well using RDM can reach the outlying reservoir (Figure 6.9) and likewise with a subsea installation (Figure 6.10).

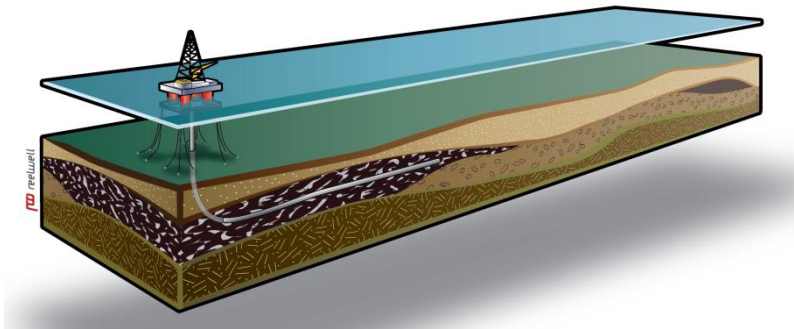


Figure 6.5 – Conventional drilling reach (Illustration. Reelwell)

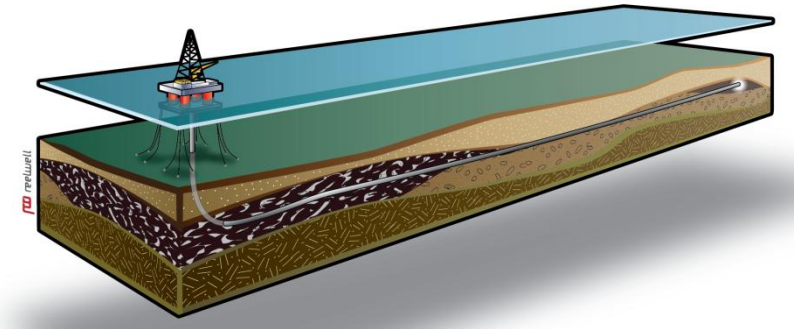


Figure 6.6 - Extended well using RDM (Illustration. Reelwell)

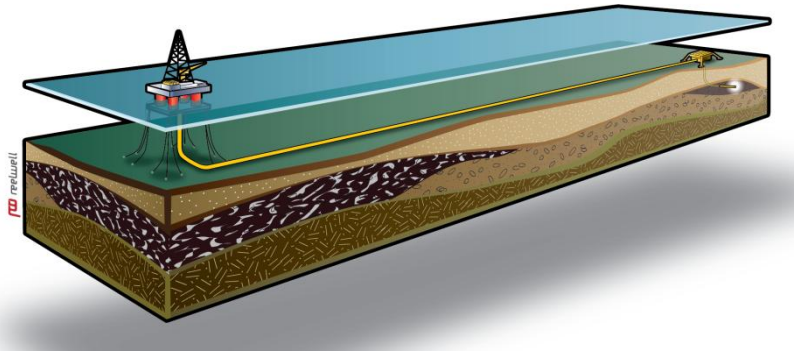


Figure 6.7 – Subsea installation with tieback to the platform (Illustration. Reelwell)

### ***Instructions FDA***

*Instructions FDA* is the first sheet in model FDA. This sheet explains what this model's case study is (comparing an extended reach well with a subsea installation), which assumptions that are made and which steps the user need to complete in order to get the NPV and production analysis in *Results: NPV* (Figure D3.1a and Figure D3.1b).

### ***Input: Key variables***

The *Input: Key variables* sheet allows the user to specify the key variables which will be later used in the model (see chapter 6.1) (Figure D3.2a). There are four key components on the sheet (Figure D3.2b): An option button for choice of system of measurement, an option button for choice of tax system, an option button for choice of model of oil and gas prices and lastly a box for inputting the discount rates.

The option button for choice of system of measurements allows the user to choose between the metric system and the US customary units. This choice affects how the historic data in the sheet *Input: Production profiles* is shown. The user is highly advised to be consistent in his or her choice of system.

The option button for tax system allows the user to either model the tax rate as an effective tax rate or model the Norwegian tax system. This affects how the tax is calculated in the *Input: Cash flows* sheet. Details on the consequences of each choice will be explained in that sheet.

The option button for choice of model of oil and gas prices gives the user a choice between using either static or dynamic oil and gas prices (Figure D3.2c and Figure D3.2d). If a dynamic oil and gas price model is chosen the user must enter the oil and gas price for each relevant year. It is beyond the scope of this thesis to allow the user to enter a formula which reflects changes in the oil and gas prices. In this thesis we have chosen to use static oil and gas prices for simplicity's sake. The oil and gas prices are used for calculating the revenue in the *Input: Cash flows* sheet.

The box for entering discount rates allows the user to enter the desired discount rate for the two investment options. The discount rates are used in the NPV calculations in the *Results: NPV* sheet.

### ***Input: Estimate cost***

*Input: Estimate cost* is the third sheet, and is where the user specifies how much he or she estimates the investment options are going to cost (Figure D3.3a). Due to limitations in Excel it is difficult to program a feature where the investment cost can be transferred to any given year in the sheet *Input: Cash flows*. *Input: Estimate cost* is the only sheet where the output (total cost of each option) has to be manually transferred to another sheet (*Input: Cash flows*). The sheet has four main components (Figure D3.3b): A table for entering the costs of RDM, a table for entering the cost of the subsea installation, a button to show/hide P10 and P90 and two buttons to allow use of a cost-breakdown structure of the cost-elements. The default mode of the sheet shows only P50 and does not use the cost-breakdown structure (Figure D3.3a).

The tables for entering the costs of RDM and the subsea installation: These tables use high-level cost-elements – rig rate, spread cost, completion, rig upgrade cost (RDM only) and subsea production system (subsea only). When the cost-breakdown structure is used (Figure D3.3c) each cost-element will show its sub-component if applicable.

The button for showing/hiding P10 and P90 is to show or hide the columns containing P10 and P90 (Figure D3.3d). The user can model the uncertainty inherent in the investment costs, and link it to P10, P50 and P90. This will be reflected in the cash flow in the sheet *Input: Cash flows*. On the other hand, the user might not want to model the uncertainty related to the investment costs, and would rather use the P50 estimates in all the cash flows. This is the reason for implementing a show/hide P10 and P90 button.

There are two buttons which together allows the user to use or not use the cost-breakdown structure. The first button is a checkbox. As long as the button is unchecked, the cost-breakdown structure with its entered values is not used and the second button is non-usable (Figure D3.3b). If the checkbox is checked, then the second button allows the user to expand or collapse the cost-breakdown structure (Figure D3.3b)



### ***Input: Production profiles***

*Input: Production profiles* is the fourth input sheet and this sheet gives the user the option to define a production profile for P10, P50 and P90. The first part of the sheet is a menu (Figure D3.4a). This menu contains seven main components (Figure D3.4b): Two components that are used throughout the sheet – a button for showing the menu and a set of useful buttons. These two components will always be visible in this sheet. The remaining five components are only visible when the menu is shown. The five components are: A set of buttons for selecting the P10, P50 or P90 input section, a cell which allows the user to specify the starting year of the profiles (if historical data is used, the starting year will be decided by that data), three boxes giving information on the P10, P50 and P90 sections, a cell for entering the total reservoir size, a cell for entering the total reservoir size, and a set of checkboxes that decides whether or not oil, gas, NGL or condensate is shown in the input section.

The set of useful buttons (Figure D3.4b) consists of:

*Load base profile:* Selects the historical data from a Norwegian oil field. This button is only usable when entering the profile to P10, P50 or P90.

*Reset profiles:* Resets all the profiles to zero. When pressed, a box will pop up, and the user must confirm that he or she wants to delete all current data.

*Link forecasts to P50:* This button links the forecasts of the base profile to P50 to those of P10 and P90. In other words, the P50 base profile forecast is copied to P10 and P90. All changes in P50 apply to P10 and P90 automatically unless the respective cells in P10 and P90 have been manually altered after the linking.

*Show production chart:* This button is a hyperlink to a different sheet (*ProdGraph*) which is used to visualize the production profiles.

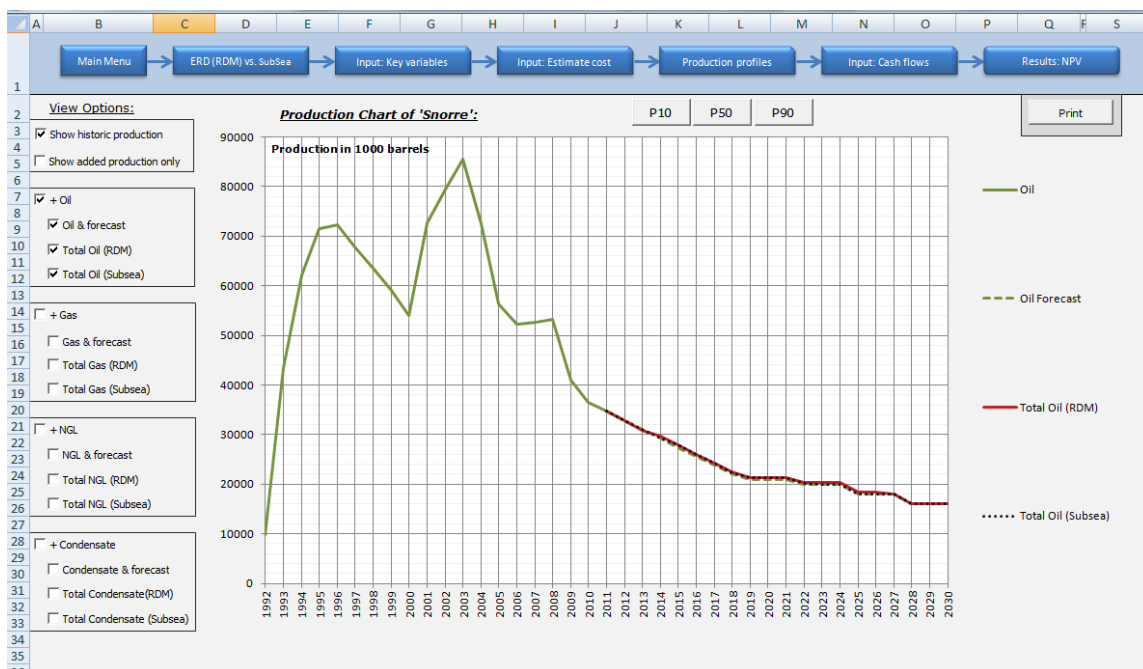
The three sections of inputting P10, P50 and P90 are functionally the same, and therefore only the section for inputting the P50 profile will be explained (Figure D3.4c). The profile contains five key components (not including the show menu button and the set of useful buttons) (Figure D3.4d). Three of the components are linked in a table. They are used for inputting the forecast to the base profile, the RDM and the subsea installation. The input section for RDM and SubSea contain the option for inputting both the added and the lost production. Being able to model lost production is important because drilling a new well from a fixed platform

implies that other maintenance work will not be performed, and therefore production will be lost or delayed. There is an output section showing the total production figures when the RDM and SubSea is added to the base profile. This information is included in order for the user to be able to check that the total production figures are correct. Lastly there is a table for inputting the assumed recovery rates for RDM and SubSea. This is an important assumption as it dictates how much oil will be recovered from the reservoir.

Important: The production profiles must be correct when the cash flows are to be entered. If the production profiles are wrong, then the NPV calculations will not be correct.

### ***ProdGraph***

The *ProdGraph* is a sheet which is used to create a dynamic capable of showing historic production, the forecast of the base production and added/lost production through RDM (Figure 6.8a) The *ProdGraph* has four components (excluding the toolbar and print button) (Figure 6.8b): A set of two checkboxes for choosing to see the historic production and/or only the added production due to RDM and Subsea, a set of checkboxes for choosing to show/hide oil, gas, NGL or condensate, a set of three buttons to choose the P10, P50 or P90 production graphs and lastly the graph itself.



**Figure 6.8a – Sheet *ProdGraph* showing oil production on the Snorre field. The sheet also demonstrates a fictional oil production forecast through 2030 with both RDM and Subsea production totals.**

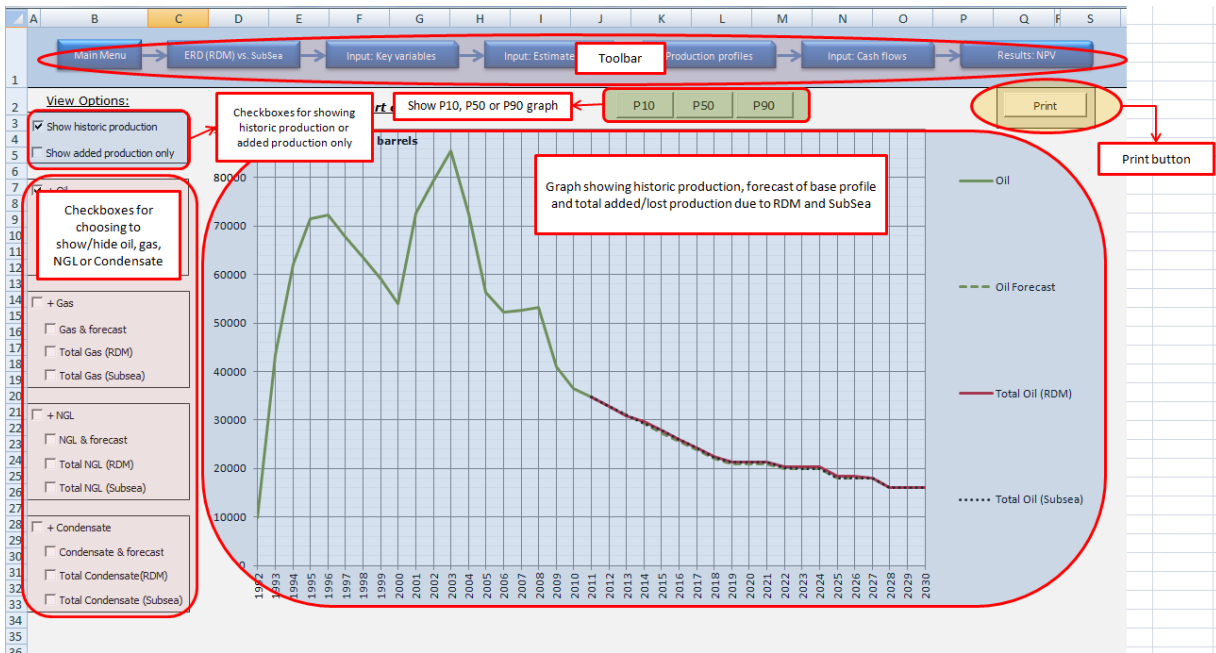


Figure 6.8b - Sheet *ProdGraph* explained.

If the historic data checkbox is checked and the “*Show only added production*” checkbox is left unchecked the historic production will be shown, and the base profile, forecast and total production due to RDM and SubSea are shown (Figure 6.8a). This configuration of the graph allows the future production to be shown in light of the historic production. Because the scale of production is very large when the historic production is shown, it is difficult to see the difference between the production to RDM and SubSea.

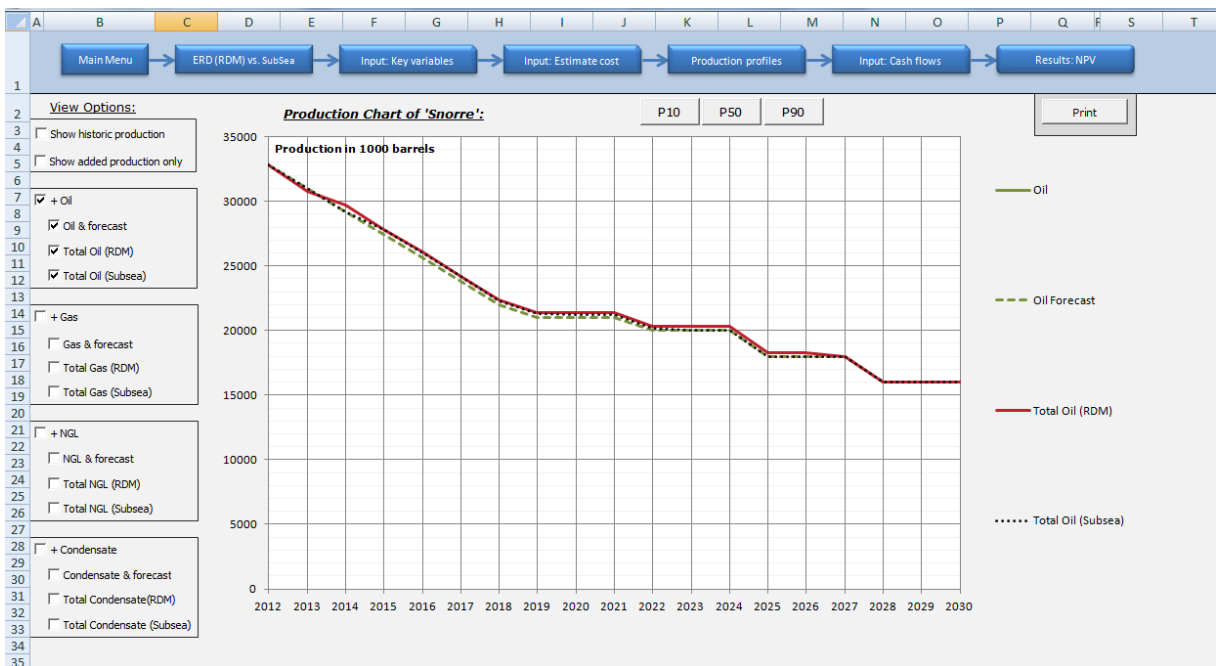
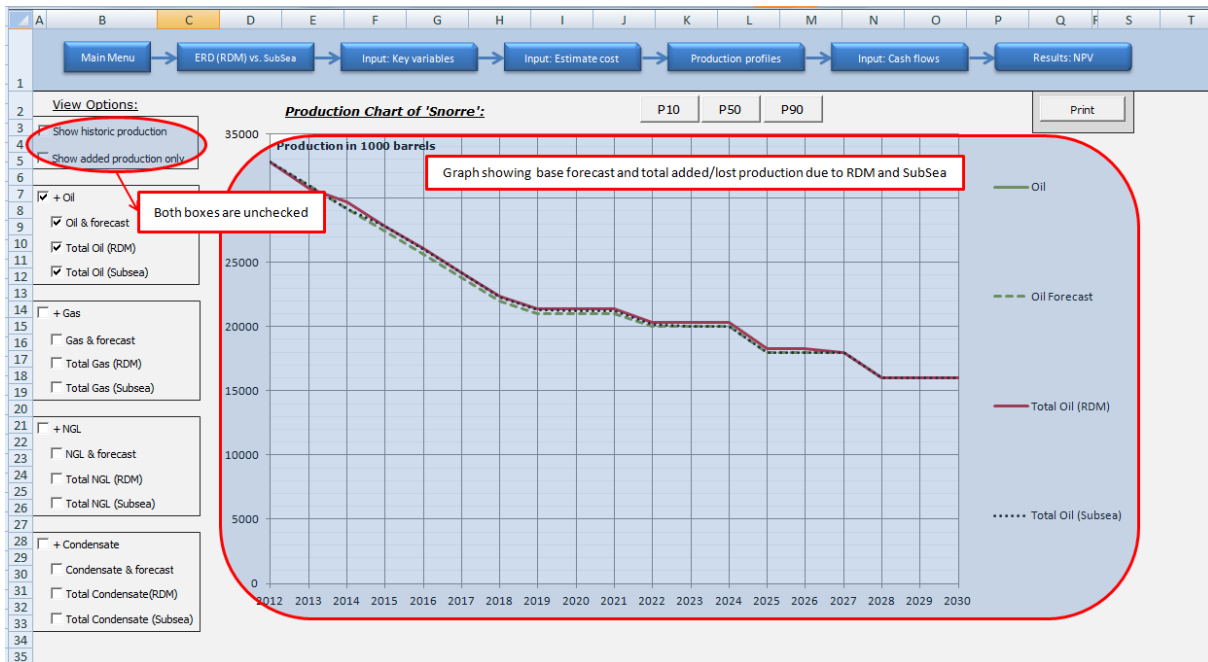


Figure 6.8c - Hiding the historic production in the sheet *ProdGraph*



**Figure 6.8d - Hiding the historic production in the sheet *ProdGraph* with the settings explained.**

If the set of checkboxes for showing historic data and added production are both left unchecked, then the base profile forecast and the total production figures due to RDM and SubSea will be shown (Figure 6.8c and Figure 6.8d). Due to the scale of production, the difference between the base profile forecast, RDM and Subsea are hard to tell apart.

If the only the checkbox “*Show added production only*” is ticked, then only the total added/lost production due to RDM and Subsea are shown (Figure 6.8d and Figure 6.8f). This configuration is the best one to show the difference between RDM and SubSea.

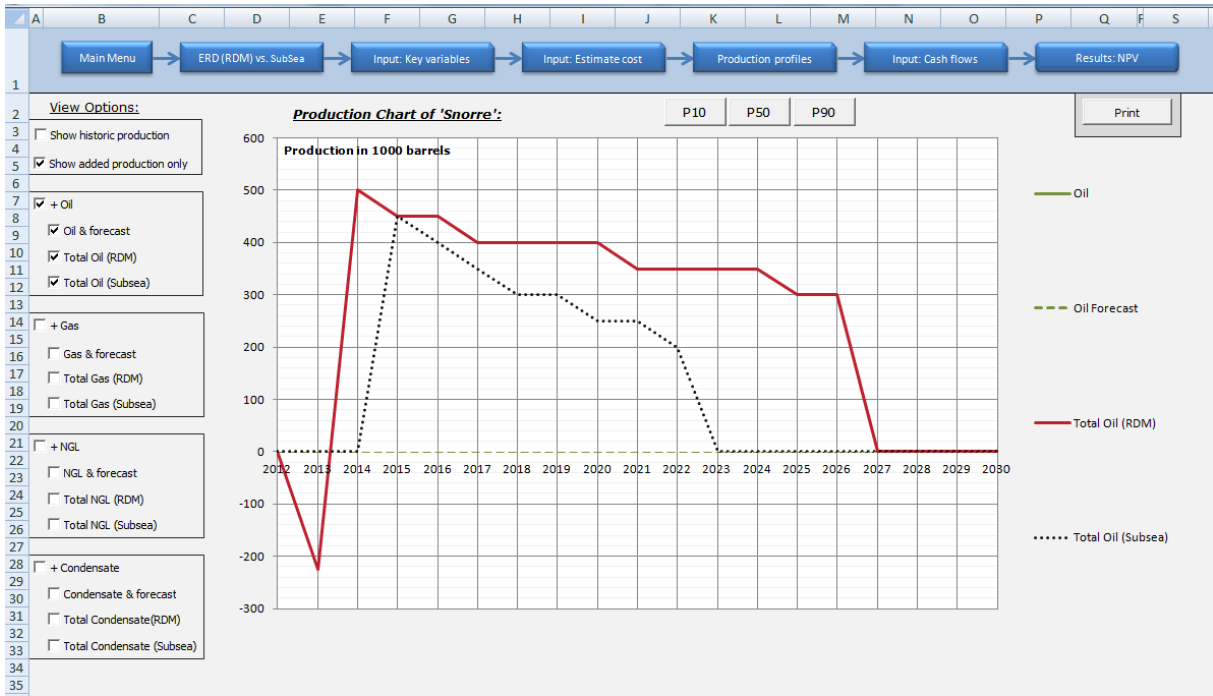


Figure 6.8e – Resolving the scale problems in the sheet ProdGraph by showing the added and lost production relative to the forecast. This solves scale problems as seen in figure 6.8a.

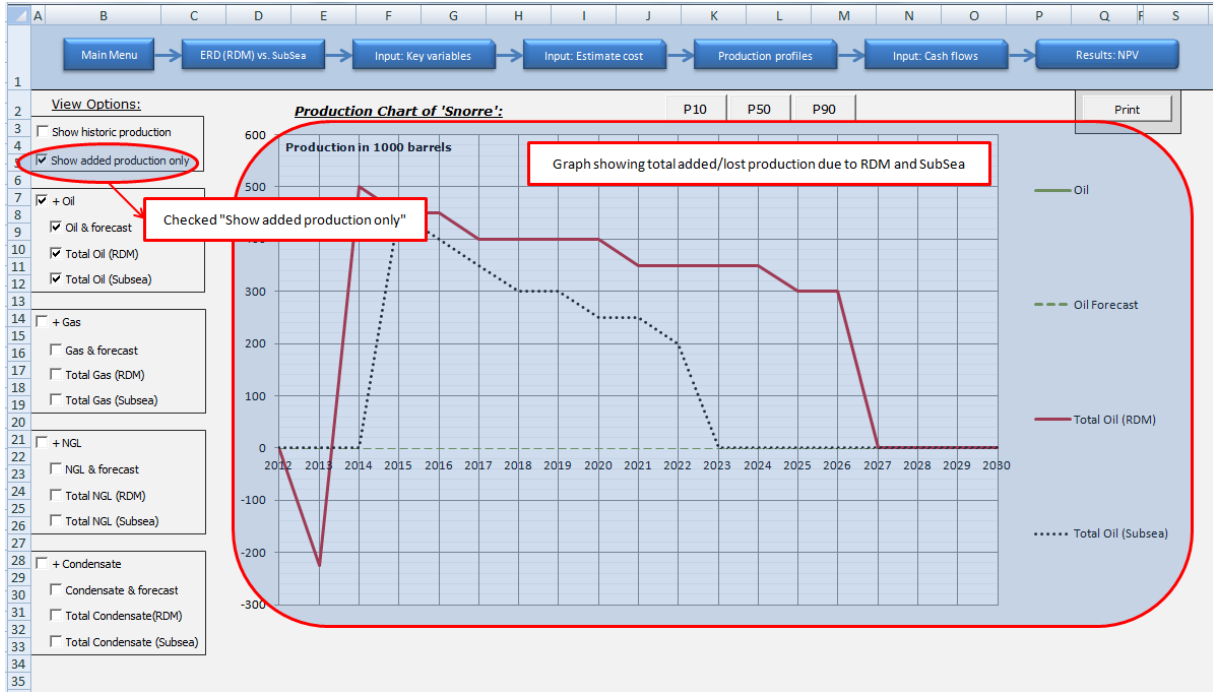


Figure 6.8f – View options explained in the sheet ProdGraph for showing added production only.

### ***Input: Cash flows***

*Input: Cash flows* is the fifth and last input sheet. The purpose of this sheet is to obtain an as correct as possible post-tax cash flow in order to calculate the NPV and IRR for RDM and SubSea. In this sheet the user will fill in the costs related to the investment options in P10, P50 and P90. As with the previous sheet, the first section of the sheet is a menu (Figure D3.5a). This menu consists of four components (Figure D3.5b): A set of three buttons which are linked to the sections where the input to P10, P50 and P90 can be filled in, a set of three textboxes with information on P10, P50 and P90, a button to return to the menu and a set of three small buttons used to select the given investment option to be filled in (no investment, RDM and SubSea).

There are a total of nine sections which need input: Three options (no investment, RDM and SubSea) for P10, P50 and P90. Because all the nine sections are functions in the same manner only one of them will be explained in detail, in this case it is the no investment option in P50 (Figure D3.5c).

There are two components of interest in the input section (Figure D3.5d): A title which explains which of the nine sections the user is currently viewing and a row which explains what exactly the viewer needs to fill in. The first column is the years which are of interest (typically starting at 2012). The second to fifth column contain the data from the production profile (total production). The sixth to ninth column contain the oil and gas prices. The tenth column is the revenue which is calculated based on the previous eight columns. The next six columns are where the user can input costs and depreciation and uplift (if applicable). The eleventh and twelfth columns are where the operation and transportation costs are to be filled in, respectively. The costs entered are the total costs for each option. In the RDM and SubSea option this means that the costs for the base-line is included. Then the thirteenth column is where the investment cost of each option is to be entered. The fourteenth column is for other costs – it is up to the user to define what “other costs” are. The fifteenth and sixteenth column are for depreciation and uplift, respectively, if the Norwegian tax system is used. If an effective tax rate is used, then these columns will be hidden. The seventeenth column shows the calculated tax, and the eighteenth column shows the calculated discretionary cash flow.

### ***Results: NPV***

*Results: NPV* is the culmination of model FDA – here the analysis of the two investment options is presented (Figure D3.6a). This sheet focuses in two things (Figure D3.6b): An analysis of the oil and gas production due to the investment options and a NPV and IRR analysis. The sheets has the option to show the P10, P50 and P90 cash flows for RDM and SubSea (Figure D3.6c).

The analysis of the production has five components (Figure D3.6d): A table showing the total production figures, a table showing the added production from the investment options, a table showing the recovery rates of each investment option, a table showing the total reservoir size and the *ProdGraph* which is a customizable graph showing the production.

The NPV and IRR section consists of five components (Figure D3.6e): A table showing the investment costs for RDM and SubSea (P10, P50 and P90), a table showing the discount rates used, a table comparing the NPV and IRR of RDM and SubSea, a graph showing the PV of RDM and SubSea and a graph comparing the NPV of RDM and SubSea.

### 6.3 The development cycles

The development of the model can roughly be divided into seven development cycles (see chapter 2). Using the structure presented in chapter 6.1, a description when each sheet was developed follows below. Chapter 6.2.1 to 6.2.7 explains each cycle in detail, and here it will be specified which author developed what. A thorough description of each model was presented in chapter 6.2.1 and 6.2.2.

An overview of the seven development cycles:

- 1) Tentative suggestion on how the *Cost estimates* in CC and FDA should look like.
- 2) First draft of the *Input: Production profiles* (single profile at this time) in FDA. First draft of *Results: Cost and time* in CC.
- 3) *Drilling programs* in CC with modifications to the results. Draft of the *Cash flows* for FDA.
- 4) Refinement of *Input: Production profiles* (expanded to choose one of three user-defined profiles) and completing the *Input: Cash flow* sheet in FDA. Creation of *Key variables* in FDA.
- 5) Creation of the *Flowchart* and the *Menu bars* on each sheet. Completion of CC.
- 6) Refine *Estimate cost* in FDA to have a spread cost. Expand *Input: Production profiles* in FDA to have three active profiles (P10, P50 and P90) and expand the *Input: Cash flows* to account for the three profiles. Change the *Results: NPV* in FDA to show the comparison and results of P10, P50 and P90.
- 7) Clean-up, debugging and creating two model cases for showing how the model functions.

See Figure D1.1a for an overview of the sheets in the model.



### 6.3.1 Development cycle 1

At the start of the development cycle a meeting was held with Reelwell. The meeting was spent on discussion the formal details around the thesis and what Reelwell expected from the model. Reelwell had unfortunately very little information regarding the cost-elements in model CC and model FDA. This created major complications in creating the value case model. A lot of time in this development cycle was spent on understanding and researching which cost-elements that was to be included in the value case model.

**Liew:** The initial draft of the cost-elements was made by Liew, and this draft was the foundation of the cost estimate for model CC and FDA. Liew went on to focus mainly on the cost-elements in model FDA.

**Viken:** Viken started working on the cost elements in model CC, and made a prototype of the sheet *Input: Fixed Costs and Rates* in Excel.

### 6.3.2 Development cycle 2

The results from development cycle 1 were presented to Reelwell at start of cycle 2. The feedback was generally positive, and only minor improvements were suggested. Improvements included changing the layout of the cost-elements and including the modification cost when using RDM as a cost-element. It also became clear that it was best to develop generic models, rather than case-specific models, due to the lack of cost and benefit data. Model FDA was decided also had to focus on the added or lost production to each investment option.

**Liew:** In this cycle Liew started developing a prototype of the sheet *Input: Production profiles* in model FDA. The prototype included only one production profile (P50). If the prototype proved successful, then it would be expanded to include more than one production profile.

**Viken:** After updating the cost-elements as suggested in the feedback, Viken started developing a prototype of the sheet *Results: Cost and Time* in model CC. Cost data in this sheet was imported from the sheet *Input: Fixed Costs and Rates*. In the sheet *Fixed Costs and Rates*, a list of drilling parameters that could vary with depth and time was created. This list was modified in later development cycles.

### 6.3.3 Development cycle 3

At the third meeting Reelwell had a better understanding of what they wanted the model to do. This time the feedback and suggestions were more specific and it became easier for the authors to develop the value case model. Reelwell handed out an anonymous example of a drilling program with a time versus depth chart. This example was used as a foundation for the sheet *Input: Drilling programs*.

Reelwell requested a graph of the petroleum production, the total production of the field (including RDM and SubSea) and the added or lost production from RDM and Subsea. Reelwell provided some information on the oil, gas, NGL and condensate pricing in order to assist with modelling the cash flows in model FDA.

During this development cycle Reelwell and the authors discussed if one workbook (one file) should be used for both model CC and model FDA, or if the models should be in separate workbooks. Reelwell concluded with that they wished for one workbook in order to minimize the amount of workbooks needed for demonstrations to potential customers. The solution was to use macros (codes) in order to make the workbook user-friendly. The danger of using one workbook to host two models is that the workbook have a large number of sheets, and this could make manoeuvring in the workbook difficult.

**Liew:** Created the sheet *Input: Key Variables*. The purpose of this sheet was to collect relevant input data such as petroleum prices, choice of system of measurement (US customary units and the metric system), choice of tax system (effective tax rate or the Norwegian tax system) and discount rates. He also set up a choice of system of measurements in the sheet *Instructions CC* in model CC.

Liew developed the sheet *Input: Cash flows*. First a prototype was created if no investment was done (called “no investment”), and then expanded to include a cash flow for the two options (RDM or SubSea). The three options were listed on three separate sheets in this cycle. The “no investment” option was important in order to establish a baseline that the two other options could be compared to. All costs and production numbers included the total costs and production on the field plus the outlying reservoir (see chapter 4.1.3).

Lastly, Liew created a draft of the *Results: NPV* in which the results from the *Input: Cash flows* were exported to. The discount rates in sheet *Input: Key Variables* were used to calculate the NPV in *Results: NPV*.

**Viken:** Viken started developing the sheet *Input: Drilling programs* based on the drilling program which Reelwell handed out. The drilling programs in the sheet gave outputs to the list of drilling parameters in sheet *Fixed Costs and Rate*. The outputs were the parameters dependent on time and depth.

Viken went on to create a simple version of the sheet later known as *ProdChart* in model FDA. The chart showed the total petroleum produced with both RDM, Subsea and “no investment”.

Lastly, Viken focused on researching Excel macro codes which could be useful in the further development cycles. This was viewed as a necessity in order to make the models more dynamic and adaptive as generic models. Viken then applied simple macros for showing and hiding rows in the sheet *Input: Drilling programs*. This feature made the sheet dynamic in that the user could specify the number of sections to be drilled, and whether or not a liner was used. . This sheet were left with minor shortages for later to be improved.

#### **6.3.4 Development cycle 4**

Reelwell were pleased with the progress during the last development cycle. They agreed with the usage of macros and the features they enabled. *Input: Cash flows* and the NPV calculations in *Results: NPV* in model FDA were approved. Likewise was *Input: Drilling programs* approved.

Improvements on the sheet *ProdGraph* were suggested, such as being able to hide/show oil, gas, NGL and condensate. They also requested IRR calculations in *Results: NPV*. The oil and gas prices in *Input: Key variables* had to have the option to enter dynamic prices in order to more accurately model the NPV and IRR. In order to have an as accurate portrayal of the uncertainty in the investment options in model FDA Reelwell expressed a wish for P10, P50 and P90 estimates in *Input: Estimate Cost* and *Input: Cash flows*. Similarly Reelwell wanted P10, P50 and P90 and model CC:

**Liew:** Liew continued working on *Input: Cash flows*. The previously three sheets (No investments, RDM, SubSea) were combined into one. Now the implemented macros allowed the user to easily select among the three options (“no investment”, RDM or SubSea). When this was complete Liew started working on implementing the Norwegian tax system in the sheet *Input: Cashflows*.

In the sheet *Results: NPV* Liew added the option to show or hide the yearly NPV by using macros linked to a button. The IRR for the different field development options was also added.

Liew started developing the *Flow Chart* on the sheet *Main Menu*, and the layout in *Main Menu* was used to develop the *Toolbars* on each sheet. The Flow Chart was made in order for the user to have an instinctive understanding of the models as a whole, and be able to quickly navigate the models. Then Liew added a toolbar to all the sheets based on the flowchart in the sheet *Main Menu*. Hyperlinks were added in the toolbar for all of the sheets. This allowed the user to select any given sheet in a model.

**Viken:** Viken continued the work on the sheet *Input: Drilling programs*. Unresolved issues were resolved such as errors in graph representation, total “test BOP” days calculations and issues in the “run and cement casing” days calculations when 6 sections were drilled using a liner. A risk analysis on time usage with P10, P50 and P90 were implemented.

Implementing P10, P50 and P90 required the sheet *Input: Costs and rates* to be updated with data from the risk analysis.

This gave output values to the sheet *Results: Cost and time* where Viken also added the possibility to hide and show P10, P50 and P90 in the results. A command button for showing and hiding the Cost-breakdown was implemented. Viken also created a cost and time comparison chart of the values P10, P50 and P90 in the sheet *Results: Cost & Time*.

When *Results: Cost and time* was complete Viken continued the work of Liew on the sheet *Input: Production profiles*. The sheet was expanded to be able to upload historical data from existing Norwegian offshore oil fields. Furthermore the sheet allowed the user to enter three user-defined profiles, the P10, P50 and P90. A matrix showed the differences in petroleum produced with the different methods of field developments. Liew later placed these matrixes in the sheet *Results: NPV*.

Viken continued the previous work on the sheet *ProdGraph*. Checkboxes for which type of petroleum produced to show in the graph was created. This allowed the user to choose which of oil, gas, NGL and/or condensate he or she wanted to see in the graph.

When this *ProdGraph* was complete Viken went on to further development of *Input: Key variables* and set up a choice between a static oil and gas price or variable with respect to the years, as requested. The chosen option was set to change the petroleum prices shown in the sheet *Input: Cash flows*.

### 6.3.5 Development cycle 5

Reelwell was pleased with the work from development cycle four. They saw the flowchart in the sheet *Main Menu* as a great overview of the models, and saw the toolbar as a neat navigation tool that gave a better understanding of the models.

This cycle was affected by a major change in the model. Previously the model assumed that only one production profile in model FDA was active at any given time, and that the user manually had to change the profile in order to see the other two profiles. Together with Reelwell the authors came to the realization that in order to accurately describe P10, P50 and P90 of the production profiles, they needed a cash flow each. In other words Model FDA needed three active profiles and three active cash flows (each cash flow including the three investment options). The *Results: NPV* needed to accommodate this fundamental change, and was redone completely to reflect this.

In order to ease the navigation in the sheet *Input: Production profiles*, it was decided to create an internal navigation menu for the sheet.

During the meeting Reelwell informed that RDM could have the possibility of using one less casing compared to conventional drilling methods, and that this should be reflected as a possibility in the sheet *Input: drilling program*. Reelwell also expressed a desire that the costs in *Input: Estimate costs* should include a spread cost.

**Liew:** Liew created cash flows for P10 and P90 in the sheet *Input: Cash flows*.

When this sheet was completed, Liew focused on the sheets *Instructions FDA* and *Instructions CC*. These sheets were created in order to give the user an understanding of the assumptions behind each model and a step-by-step explanation of how to use the models.

**Viken:** Viken continued working on model CC and started debugging and fixing minor problems. Viken also created a check box for skipping a section when using the RDM in *Input: Drilling programs*.

Viken then created a menu for navigating through the different production profiles in the sheet *Input: Production Profiles* for ease of use. A series of checkboxes was also created in order to simplify the input of the different petroleum produced. If the same forecast in production were to be used in all the three profiles, an option to “link” the forecasts was created.

When Viken had finished *Input: Production profiles*, he improved the *ProdGraph* further. The chart now had the opportunity to show only added and lost production from Subsea and RDM relative to the forecast. An option to choose between P10, P50 and P90 was enabled in the production graph.

Viken applied the same feature to the production graph in the sheet *Results: NPV*. Lastly he created a graph showing the NPV to RDM and subsea. This graph compares the NPV ranges of P10, P50 and P90.

### 6.3.6 Development cycle 6

**Liew:** Liew changed *Input: Estimate cost* sheet. The function of whether to use simple spread costs or a more detailed cost breakdown was added. When this was done Liew went on to start working on the *Results: NPV* where the yearly NPV for P10 and P90 was added to the option “Show yearly NPV”.

**Viken:** Viken changed the *Input: Production profiles* and the production graph further so that settings from the sheet *ProdGraph* all applied to the production graph he placed on the sheet *Results: NPV*. Viken then went on debugging and checking that all the functions on the sheet *Input: Key variables* functioned properly. He also fixed minor and major bugs that might appear throughout of the model such as return on tax if the cash flow were negative in the

sheet *Input: Cash flows*. Also all years were set to adapt the system clock in the model FDA. This enhances the model to be usable in year 2013 and so on.

### **6.3.7 Development cycle 7**

Reelwell gave suggestions to sensitivity analysis e.g. how much can the petroleum production be reduced before the field development is not profitable, and more. Furthermore Reelwell also wished for a tutorial on how to use the model, and a model intended for demonstrations with potential customers. These were all good suggestions, but the workload involved was so high that the authors deemed it appropriate to implement these features after the thesis was delivered to UiS. In order to continue developing the model after the thesis was complete Reelwell decided offer the authors a summer job which was accepted.

This cycle was devoted to debugging, testing and improving the help functions of the model. Additional cell validations were written. Errors in specific inputs would give the user feedback on this as an error message explaining the problem and solutions. Many macros were rewritten in order to make them easier to run in the worksheet. This created the impression of a smoother and quicker workbook. It was checked that all input and output values had legends showing the right value format. The FAQ section was further updated and a simple search function for key words was added. The sheets in the workbook were protected from editing, and only input cells were set as selectable. A userform enhancing the printing of the sheets through macros were added in order to make printed reports of the model easier.

The work done in this development cycle was of the type that is difficult to specify whom did what. Most of the debugging had to be double-checked by both authors independently in order to be sure that no mistakes had been done. At this stage the model was of sufficient complexity that both authors were needed if changes were to be implemented.

## **7. Discussion**

### **7.1 What can the models actually do?**

There is a distinct difference between what a model does, and the applications a model have. This chapter will discuss what the models actually do, and the next chapter will discuss the applications of the models.

Model CC can be used to compare two different drilling programs and analyze the differences in cost and time. In this thesis the drilling programs have been restricted to a drilling program using RDM and a drilling program using conventional equipment. Model CC can however, be used to compare any two drilling programs.

Model FDA can be used to compare two possible investments with respect to field development and analyze the production, NPV and IRR. In this thesis the investment options are limited to the comparison between an extended reach well (RDM) and a subsea installation. Both the options are assumed to drill in the same outlying reservoir, and thus adding to the overall production of the given field. Model FDA has the capability of analyzing any two investment options that add to the production of a field. This includes drilling additional wells, drilling an injection well, and so on.

### **7.2 Usage and limitations of the model**

The models have a much broader application than initially assumed. The initial scope was to analyze two specific cases, but as the development cycles wore on it was discovered that the models could analyze generic cases (see chapter 7.1). The advantages of being able to analyze general problems are vast. One apparent advantage is that there is no need to develop a model for each specific case – these two models are sufficient if the cases fall within their scope. Another advantage is that the models can be used for scenario modeling (most relevant for model FDA).

Model CC can be used to establish a most probable case (with P10, P50 and P90). This case includes the systematic risk which the user is aware of. In order to model unsystematic risk such as new regulations on drilling, drastic changes in rig rates, etc, scenarios are needed. The most probable case is saved as one file, and other files will be used to model each of the other unsystematic risk factors (alone or together). This way a more thorough analysis of the drilling options can be made. The best drilling model might not necessarily be viable if an



unsystematic risk factor should occur. New drilling regulations might make one method unviable due to increased costs.

Model FDA can likewise be used to establish a most probable case, and then use this case for modeling unsystematic risk. The unsystematic risk factors are many; examples include war, new or revised legislation, economic recession and gross miscalculations of the oil reserves. Using more than one file allows the user to experiment with how different risk factors would affect the investments.

Limitations in model FDA lies in the base assumptions behind the model. The model assumes that the reservoir size is fixed, and that only the rate of recovery can vary. In reality the reservoir size is uncertain, and in order to account for this the user can for instance use more than one file or to use Monte Carlo simulations (see chapter 3.7). If more than one file is used, a risk matrix is in effect created (Figure 7.1). Otherwise a Monte Carlo simulation can be used to define a distribution of how much oil and gas is recovered. Using a Monte Carlo simulation like this would involve rebuilding the model somewhat.

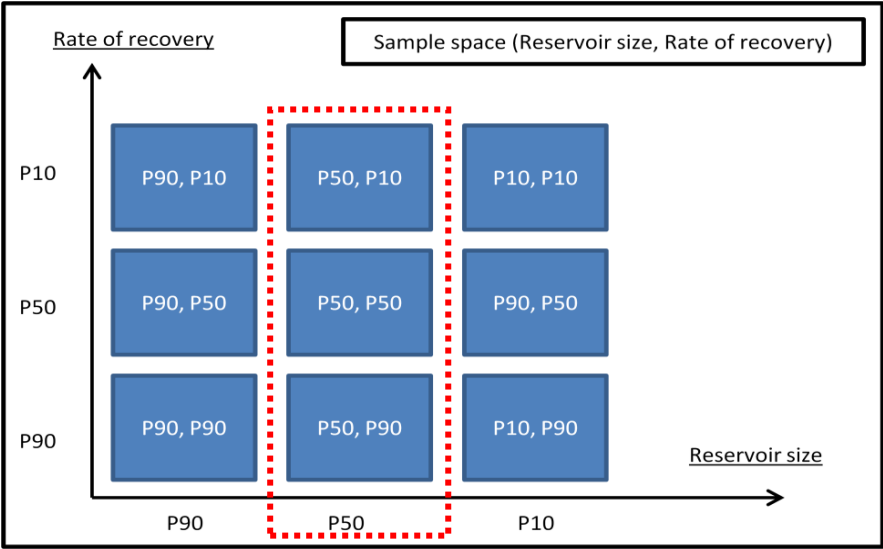


Figure 7.1: Sample space (Reservoir size, Rate of Recovery)

If three files with model FDA (given a P50 reservoir size) are used, then the sample space within the red dashed frame in Figure 7.1 is obtained.

## **7.3 Post-thesis development of the model**

### **7.3.1 On copyright and usage of the model**

The model presented in this thesis is the copyright of the Reelwell and the authors. Any usage of the model needs permission from the copyright holders.

### **7.3.2 General ideas for continued work**

Currently the model is made with Reelwells product in mind, and the naming conventions and explanations in the model reflect this. Further potential development involves modifying the model to become generic, and have a higher focus on users who have a non-technical background. Others possible options are making the model more suitable for educational purposes and apply the model on real-life cases. After applying the model on a real-life case it would be interesting to verify the findings through Rushmore Reviews (see chapter 3.4).

### **7.3.3 Continued development for Reelwell**

The model produced in this thesis is made to solve a specific need today. In other words the model capable of comparing different drilling methods and field development options given today's knowledge. But, the coding and hidden sheets where not made with updatability in mind – the workload involved with this was outside the original scope. Technology changes, and the way the comparisons are made in this model might become outdated at a later time. In order to not lose the resources invested in the model, the user must be able to update and change the model as necessary. Furthermore, the model needs to be polished, a user manual must be written and an extensive help function must be implemented in order for the model to be used to introduce a product (such as RDM).

Reelwell was interested in making the model commercially viable in the sense that they wanted to be able to use the model when presenting their product to potential customers. They decided to hire the authors for one month in order to continue developing the model after the thesis was delivered to UiS.

The main elements which we are to implement while employed by Reelwell's are the following:

- 1) Rewrite the hidden sheets and codes in such a way that a 3<sup>rd</sup> party is able to update or change the model as desired.
- 2) Write an extensive "frequently asked questions" (FAQ) section, and code help functions on the individual sheets.
- 3) Make a tutorial for new users (potentially in PowerPoint).
- 4) Make a model intended for demonstrations with potential customers.
- 5) Give the model a distinct "Reelwell-look". This involves re-designing the model to have the same design principles as Reelwell's webpage.

Our initial estimate of the time needed to complete this scope is one month.

## 8. Conclusion

The objective of the thesis was to develop a value case model which could show the potential benefits of RDM, and was intended for use within Reelwell and potential customers. The final model fulfils in part the objective: it is able to show the potential value to RDM and is suitable for use in Reelwell. On the other hand, the final value case model is not suitable for use by potential customers – the model needs more polishing in order to be a commercial product. The reason that the value case model was not finished as a commercial product was due to the fact that the initial scope of the model was expanded.

At first the scope of the value case model was to analyse two specific cases: analyse two drilling programs (model CC) and two field development options (model FDA). Later the scope was expanded and value case model had to be able to compare any two drilling programs and analyze any two field development options. The value case model makes no distinction between onshore and offshore cases – the model can handle both equally well. The advantage for Reelwell is that the added flexibility allows them to analyse more cases without having to rebuild the model each time. Reelwell viewed the added flexibility as more beneficial than having a commercial product at the end of the thesis. In order to make the value case model commercial they hired the authors after the thesis was completed.

The flexibility of the model is especially apparent in model FDA. Model FDA allows the user to compare any two field development options and change the base assumptions as desired. Options of interest include extended reach wells, subsea installations, injection wells, using more than one well and multilateral wells. Being able to change the base assumptions such as oil and gas prices, rates of recovery, choice of tax system and production profiles makes model FDA suitable for scenario modelling. Scenario models are cases where the project is subject to unsystematic risk such as war or financial crisis.

The conclusion is that the value case model is suitable for use within Reelwell, but not ready for use towards customers. As of yet value case model is best suited for high-level feasibility studies, high-level cost comparisons between different investment options and as a tool for compiling information about drilling projects.

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## Appendix B – Offshore Installations

Offshore drilling rigs fall into one of the following categories:

- Barge rigs
- Submersible rigs
- Jack-up or self-elevating rigs
- Semisubmersible rigs
- Drillships
- Structure rigs

**Barge rigs:** A flat-bottomed vessel with a shallow draft. It is usually equipped with a derrick and other necessary drilling equipment. Lacking self-propulsion it is towed to its location and the hull is then filled with water, allowing it to rest on the bottom – providing a solid foundation for drilling activities. The water-depth operating range is less than 3-6 m (Donohue and Lang, 1986, p. 14.).

**Submersible rigs:** The submersible rig is a larger version of the barge rig and has a water-depth operating range of 5.5-21m (Donohue and Lang, 1986, p.14).

**Jack-up rigs:** A jack-up rig is a self elevating drilling rig, which have three to five legs that are either vertical or slightly angled for stability. The jack-up is usually towed to its location, where the legs are lowered until they rest on the seabed, and the deck is level (usually around 18m above sea level). The water-operating depth is from 9-107m (Donohue and Lang, 1986, pp. 14-15).

**Semisubmersible rigs:** These rigs do not rest on the seafloor. They are kept floating due to submerged pontoons, and kept stationary by anchors, mooring lines and position-keeping propellers. They can either move under their own power or be towed to their location. Their water-operating depth is 6-750m (Donohue and Lang, 1986, p.15) (COSL, 2010). New ultra-deepwater semisubmersible rigs can have a water operating depth can operate at water depths of 3000m (Transocean, 2012). The limitations are capabilities of the mooring equipment and the riser (the conduit that connects the drill floor to the subsea equipment on the seafloor).

**Drillships:** These are self-propelled vessels that can drill in water depths from 5 to 2700+m (Transocean, 2006)., and are the most commonly used vessel for extreme deepwater drilling at remote locations. Like the semisubmersible rigs the drillship needs anchors, mooring lines and dynamic positioning equipment (Donohue and Lang, 1986 , p.15)

**Structure rigs:** These kinds of rigs are mounted on a fixed drilling and production platform. Common designs include piled-steel platforms, concrete gravity structures (common in the North Sea), caisson-type monopod structures, guyed towers and tension leg platforms. (Donohue and Lang, 1986 , p.16)

## Appendix C – Drilling problems

Common problems that occur when drilling a well:

- Differential sticking
- Sloughing shale
- Poor mud properties
- Fatigue failures
- Foreign objects
- Poor hole cleaning
- Loss of circulation
- Stuck pipe
  - o Key seating
  - o Packoff from poor hole cleaning

### Differential sticking.

Differential sticking is caused by a differential in pressure between the drilling fluid and the formation. More specifically, differential sticking happens when the pipe remains motionless (even for a short time) – such as when a connection is made. The pipe will rest on the side of the hole, pressing through the filter-cake and contacting the formation face. The filter-cake blocks communication of the mud-column pressure to the area where the pipe contacts the formation. The result is a differential in pressure between the mud column pressure on the inside of the hole and the formation pressure on pipe. The pipe will be pressed against the side of the hole with such force that it cannot be moved (Conaway, 1999, pp. 115-116) (Figure C1).

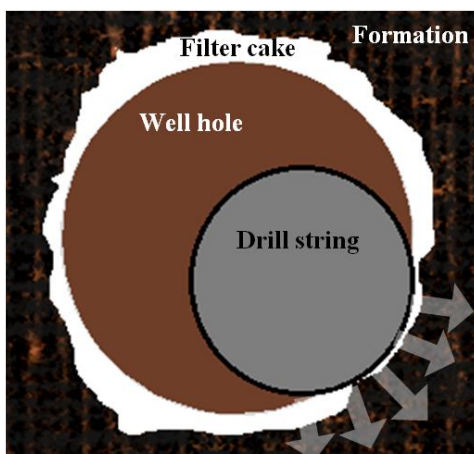


Figure C1 – Cross section of a well hole where differential pressure between the mud column and the formation presses the drill string against the side of the well. (Photo: Viken, Ø)

**Sloughing shale.**

When shale carvings break off from the sides of the wellbore, the carvings form “bridges”, or tight spots, when they gather at bends in the hole – causing the pipe to stick as a result (Donohue and Lang, 1986, p.40).

**Poor mud properties.**

The result of poor mud properties is excessive mudcake build-up on the walls of the hole or an inability to hold the cuttings in suspension when the circulation stops. Either problem can result in the drillstem being wedged in the hole (Donohue and Lang, 1986 p.40).

**Fatigue failures.**

High stresses in the drill string cause metal fatigue, and result in “twist off”, or break in two. The result is that a portion of the drill string is left in the hole, and a fishing job is necessary to remove the portion before a new drill string can be used (Donohue and Lang, 1986 p.40).

**Foreign objects.**

Examples of foreign objects are tool that workers drop into the hole accidentally, and pieces of the drill bit that gets broken off. No matter the reason for an unplanned hard object, the foreign object must be removed before drilling can be continued. (Donohue and Lang, 1986 p.40)

**Poor hole cleaning.**

Efficient removal of cuttings is an important area of focus during a drilling operation. Poor hole cleaning might cause drilling complications such as poor rate of penetration (ROP), creation of hole-pack-off, differential sticking problems, significant change in mud properties and increased formation damage potential in the drilling fluid (Qahtani, Amanullah and Aramco, 2010, p.1).

In order to maintain proper hole cleaning efficient management of mud properties is paramount. This is especially the case when drilling high-angle and horizontal extended-reach wells. Years of operational data indicate that hole-angles between 30° and 60° creates the

most difficult hole cleaning conditions when using conventional technology. At these angles local stationary cutting beds might form avalanches along the curved section of the well, creating large cuttings accumulations with high risk of stuck pipe situations (Mitchell, 2006, p. 103).

### **Loss of circulation.**

Loss of circulation with regards to a drilling fluid is defined as a reduced or total absence of flow when the fluid is pumped through the drill string. The cause of lost circulation is drill fluid leaking into the formation due to natural or induced fractures, vugular formations like chalk and limestone, or formations with high porosity and/or high permeability (Mitchell, 2006, pp 99-100).

The consequences of loss of circulation can be differential sticking if a differential in pressure is created at the loss zone, and flows or kicks if the loss causes the hydrostatic pressure to drop.

To prevent loss of circulation the conventional solution is to add lost-circulation materials (LCM) to the drilling fluid. LCM is added as a routine if it is probable that lost-circulation zones exist (Mitchell, 2006, p. 95).

### **Stuck pipe.**

#### **- Key seating.**

“Key seating, which occurs in very crooked holes when the drillpipe cuts into the wall of the hole creating a slot that grips the pipe when a tool joint or wide drill collar is pulled out.” (Donohue and Lang, 1986)

#### **- Packoff from poor hole cleaning.**

The wellbore is plugged around the drillstring – commonly caused by wellbore wall collapse or that the drilling fluid does not properly transport the cuttings and carvings out of the annulus. When the well packs off there is a loss of ability to circulate, and high pump pressure follows. The result is a stuck pipe unless prompt action is taken (Schlumberger, 2012b).

## **Appendix D - Value Case Model Screenshots**

This section shows figures which are considered too big to fit in the description of the spreadsheets in the Excel models in section 6.2 and 6.3. The following figures are also rotated in order to make details more visible by filling the whole page.

In order to make the screenshots easier to understand, the first screenshot of a spreadsheet will always show the entire spreadsheet. The second screenshot will be a copy of the first, but with explanations of which main components are present. The remaining screenshots of the given sheet will be used to highlight areas of interest.

The figures are listed in the order they are referred to through section 6.2 and 6.3.

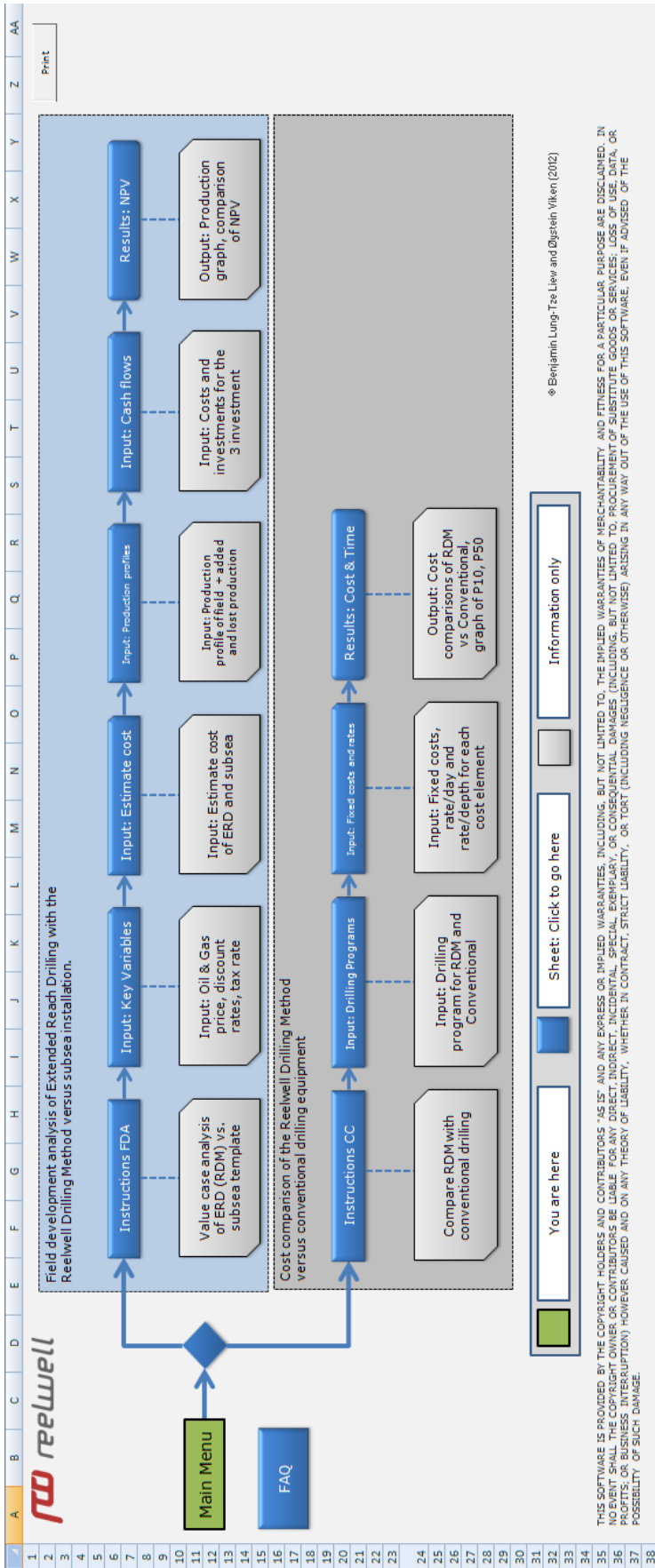


Figure D1.1a – Main menu shows an overview of all the sheets in the model.



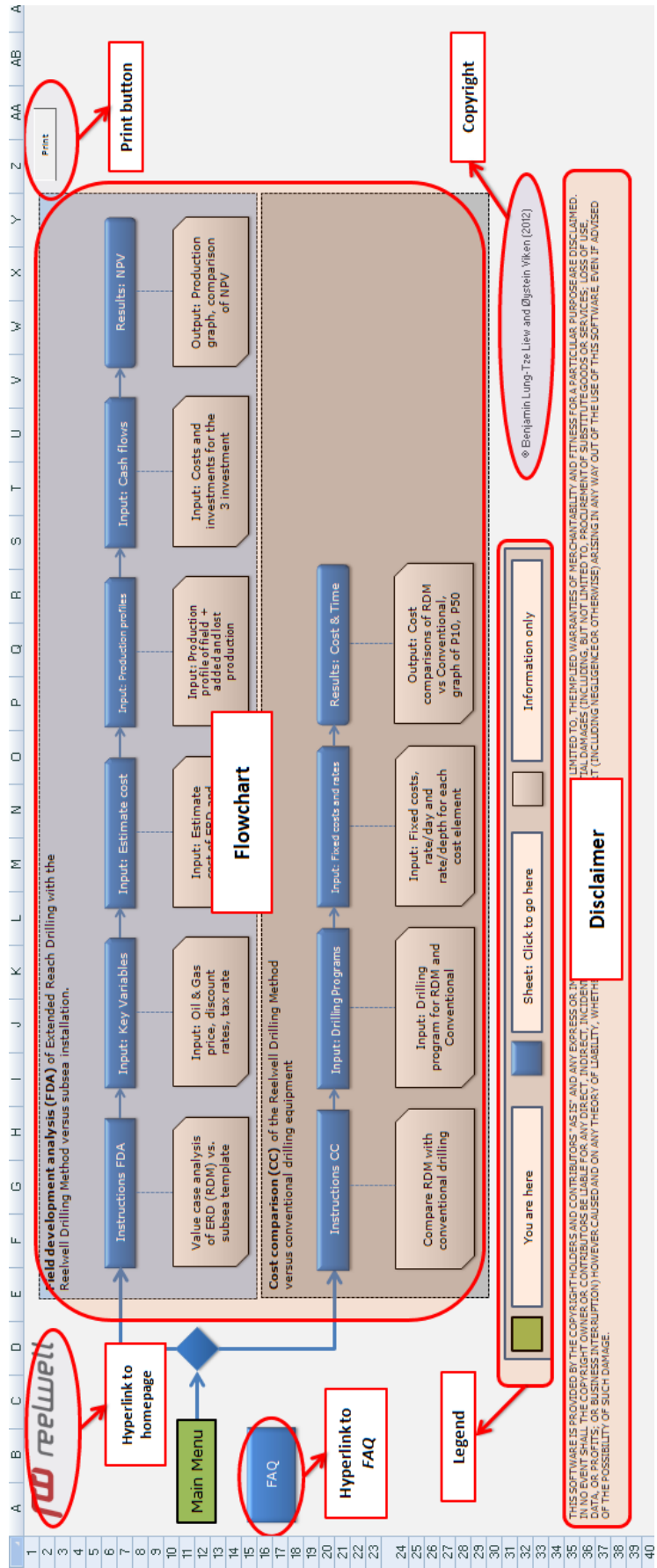


Figure D1.1b – Main menu

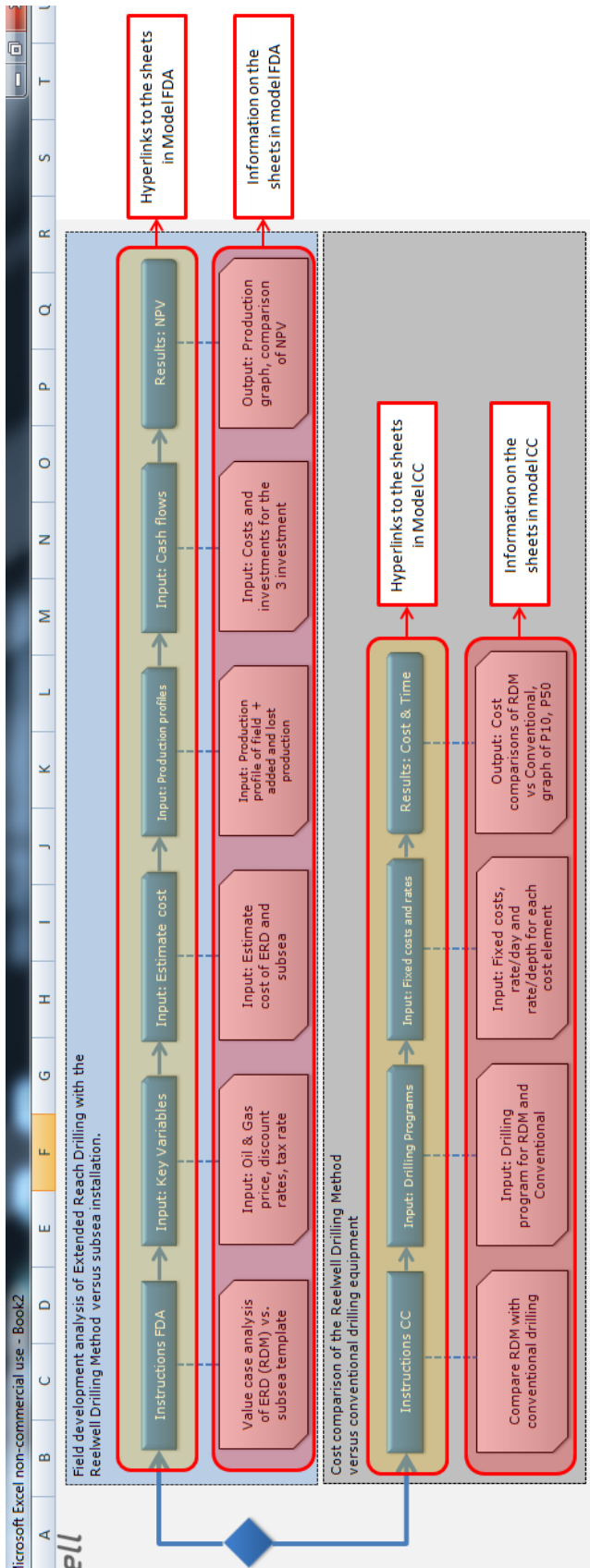


Figure D1.1c – The flowchart in the sheet *Main Menu* explained.

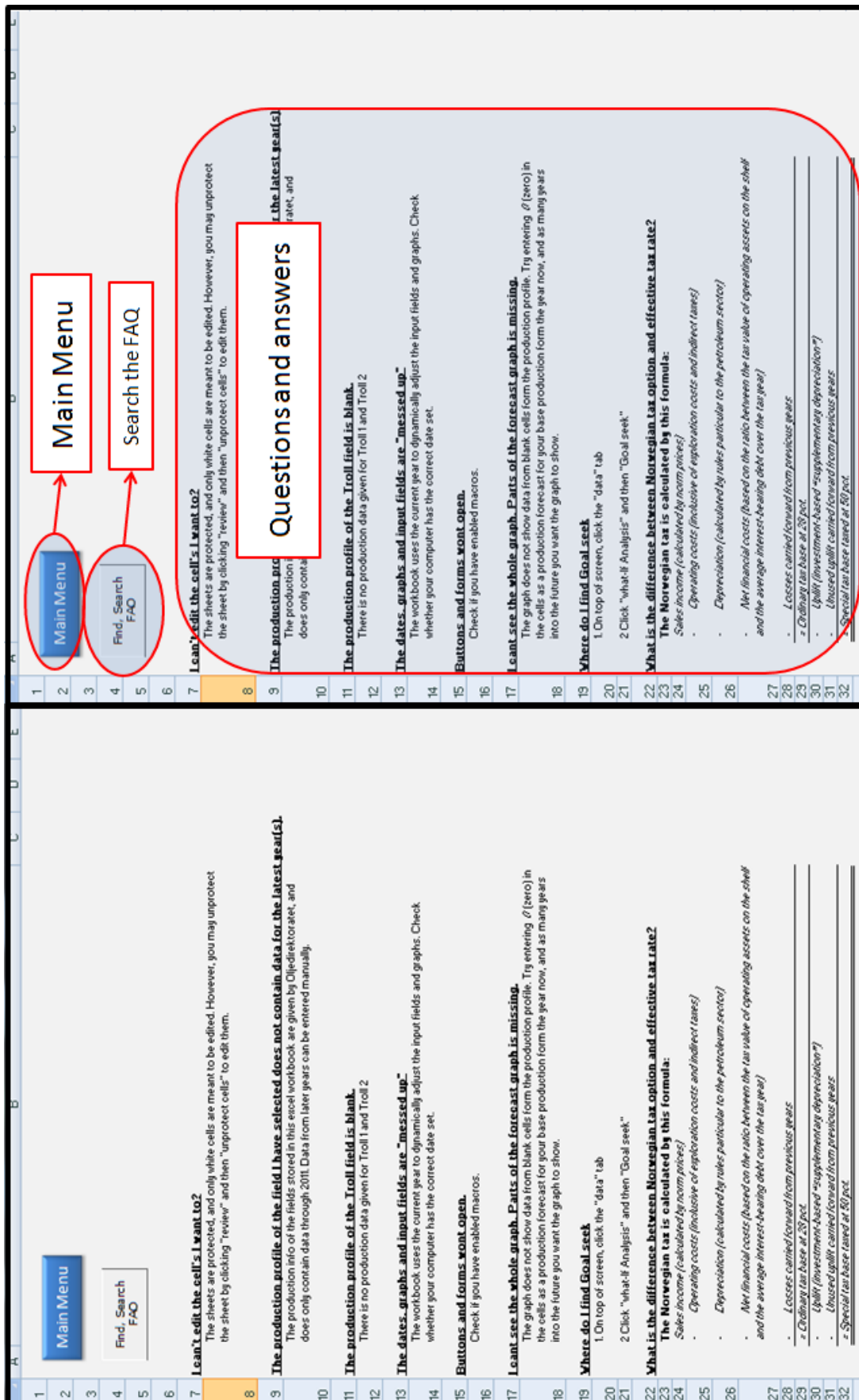


Figure D1.2 – The sheet *FAQ* shows a list of possible problems and questions the user may encounter with possible solutions.

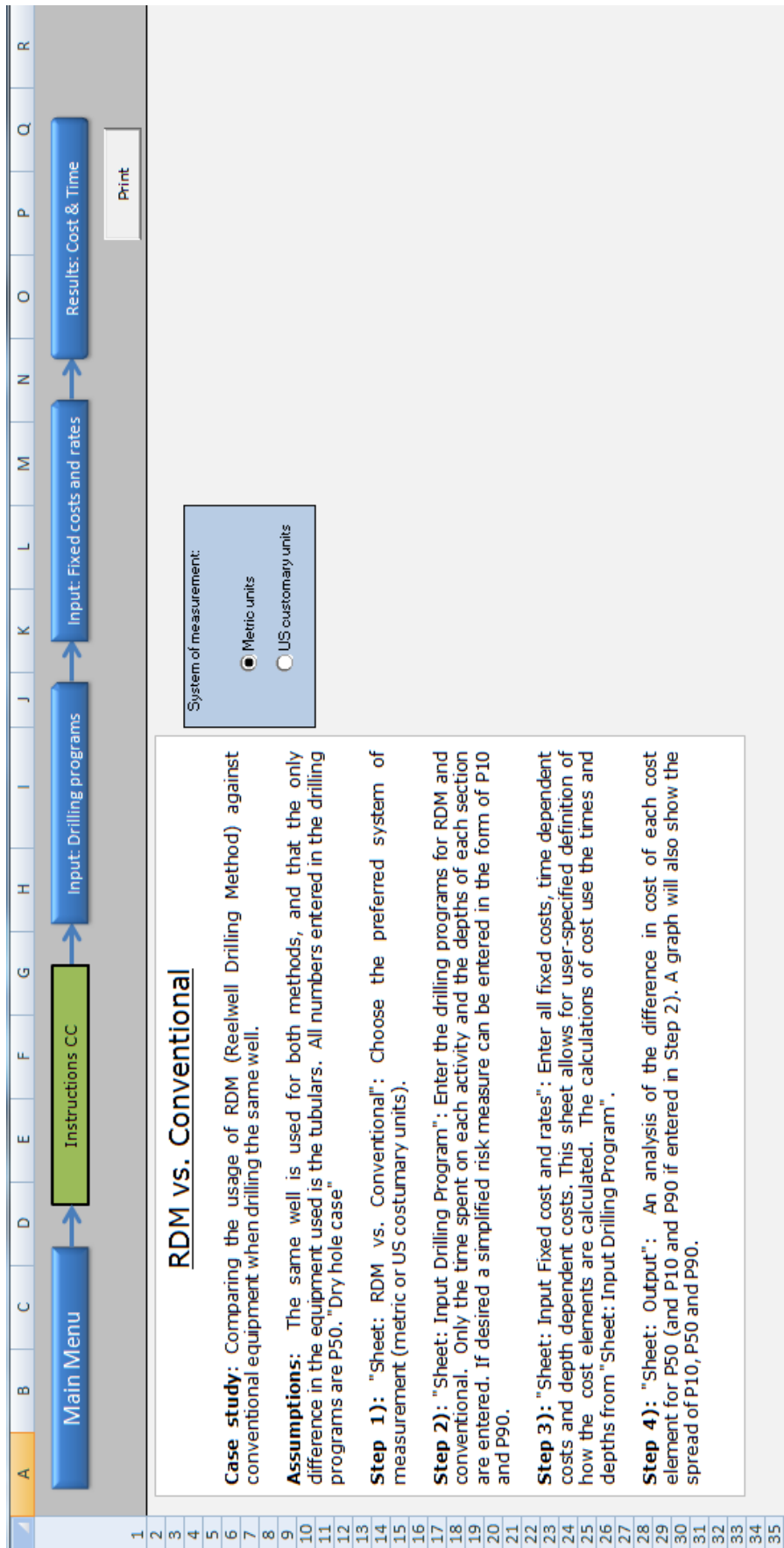


Figure D2.1a – Instructions CC

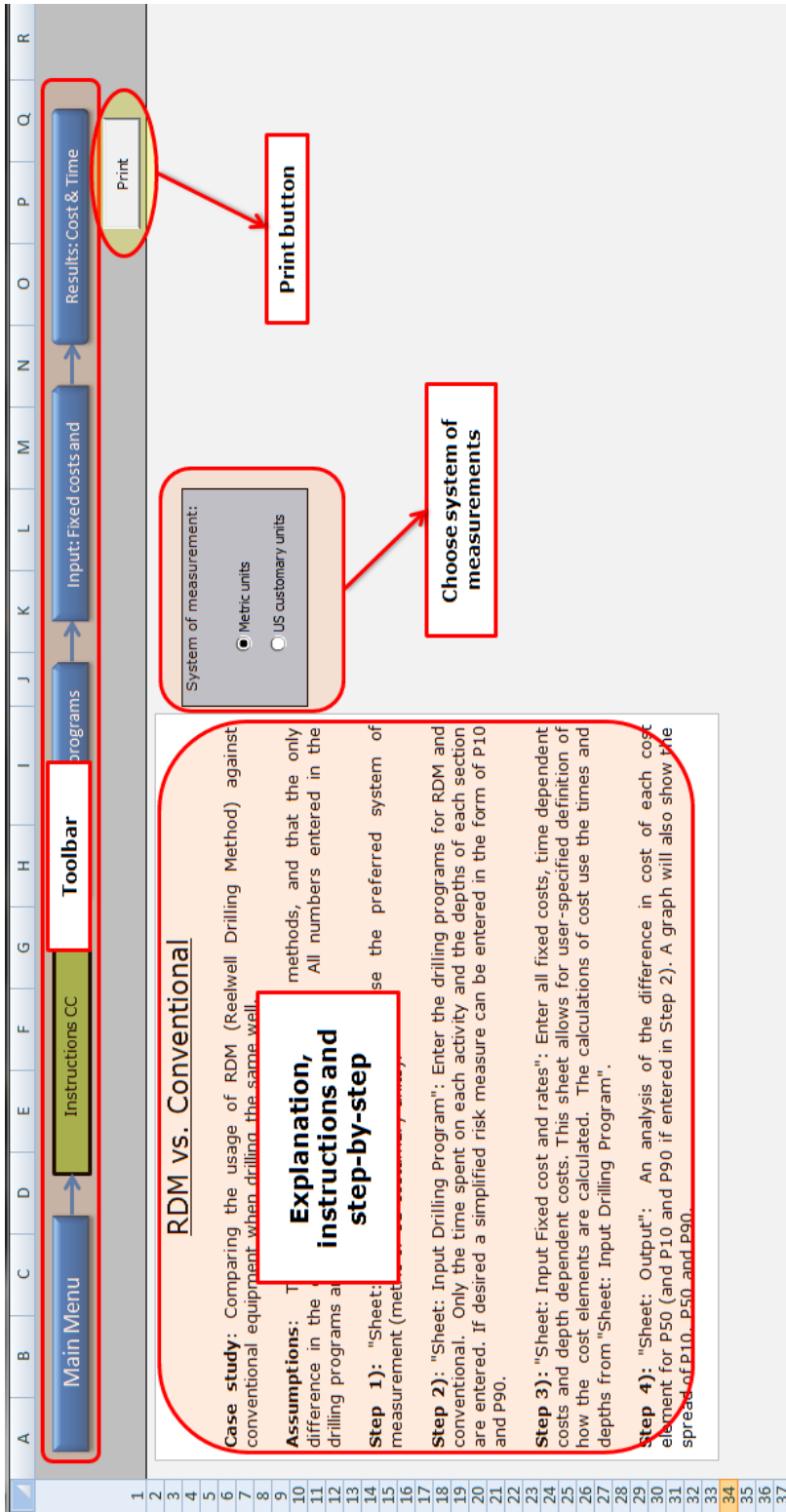


Figure D2.1b – Instructions CC

ABCDEFGHMNOT

1234567891011121314151617181920212223242526272829303132333435363738394041424344454647484950515253545556

Main MenuInstructions CCInput: DrillingInput: Fixed costs and ratesResults: Cost & TimePrint

Show P10Show P90P50

**Rig**  
Rig Costs: All included

**Subsurface services (grouped)**  
Run and cement surface casing  
Directional Drilling Services (opt)  
Wireline Logging (open and cased hole)  
Mudlogging  
Fishing, Milling and P&A Services

**Fluids (grouped)**  
Cementing services  
Drilling Fluids & Mud Engineering  
Drilling Waste Management (Opt)  
Other Major Services (Opt)

**Wellhead Equipment & Services**  
Casing and Tubular Running Services  
Casing & Liner  
Tubulars (Conventional)  
Tubulars (RDM)  
RDY Services

**Logistics**  
Helicopter  
Standby Vessel  
Supply Vessel  
Anchor Handling Vessels / Pre-laying of anchors  
Logistics (base)

**RDM upgrade cost**

|    | Conventional | RDM | Difference |
|----|--------------|-----|------------|
| 0  | 0            | 0   | 0          |
| 22 | 22           | 20  | 2          |
| 50 | 50           | 43  | 7          |
| 20 | 20           | 22  | -2         |
| 10 | 10           | 10  | 0          |
| 5  | 5            | 5   | 0          |
| 35 | 35           | 28  | 7          |
| 25 | 25           | 24  | 1          |
| 32 | 32           | 33  | -1         |
| 5  | 5            | 5   | 0          |
| 55 | 55           | 52  | 3          |
| 20 | 20           | 18  | 2          |
| 30 | 30           | 42  | -12        |
| 3  | 3            | 3   | 0          |
| 2  | 2            | 2   | 0          |
| 6  | 6            | 6   | 0          |
| 11 | 11           | 11  | 0          |
| 20 | 20           | 20  | 0          |
| 25 | 25           | 25  | 0          |

|      | Conventional | RDM  |
|------|--------------|------|
| 3    | 3            | 3    |
| 4    | 4            | 4    |
| 3    | 3            | 3    |
| 16   | 16           | 13.5 |
| 6    | 6            | 3    |
| 7    | 7            | 7    |
| 2    | 2            | 2    |
| 0    | 0            | 0    |
| 35   | 35           | 28.5 |
| 47   | 47           | 40.5 |
| 8100 | 8100         | 8900 |
| 2900 | 2900         | 2900 |

Figure D2.2a – Input: Fixed costs and rates

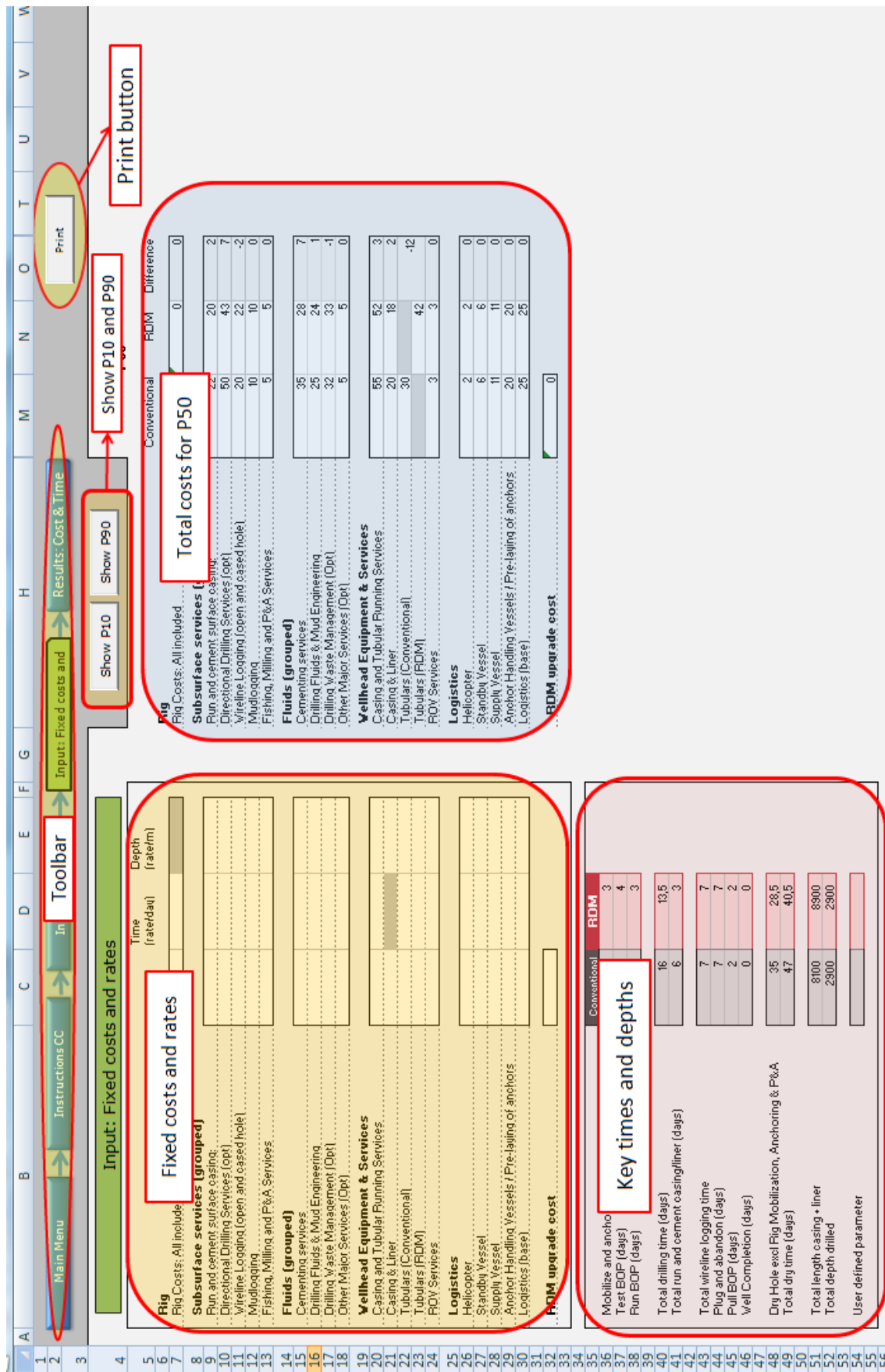


Figure D2.2b - Input: Fixed costs and rates

|    | A | B         | C               | D               | E                    | F | G | H | I | J | K | L | M | N | O | P | Q     | R     | S | T |
|----|---|-----------|-----------------|-----------------|----------------------|---|---|---|---|---|---|---|---|---|---|---|-------|-------|---|---|
| 1  |   | Main Menu | Instructions CC | Input: Drilling | Results: Cost & Time |   |   |   |   |   |   |   |   |   |   |   | FALSE | FALSE |   |   |
| 2  |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 3  |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 4  |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 5  |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 6  |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 7  |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 8  |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 9  |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 10 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 11 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 12 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 13 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 14 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 15 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 16 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 17 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 18 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 19 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 20 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 21 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 22 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 23 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 24 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 25 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 26 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 27 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 28 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 29 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 30 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 31 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 32 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 33 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 34 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 35 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 36 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 37 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 38 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 39 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 40 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 41 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 42 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 43 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 44 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 45 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 46 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 47 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 48 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 49 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 50 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 51 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 52 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 53 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 54 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 55 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |
| 56 |   |           |                 |                 |                      |   |   |   |   |   |   |   |   |   |   |   |       |       |   |   |

|  | Fixed | Time (total/day) | Depth (m) |
|--|-------|------------------|-----------|
| <b>Rig</b>                                     |       |                  |           |
| Rig Costs: All included                        |       |                  |           |
| <b>Subsurface services (grouped)</b>           |       |                  |           |
| Run and cement surface casing                  |       |                  |           |
| Drilling Services (Opt)                        |       |                  |           |
| Wireline Logging (Open and closed hole)        |       |                  |           |
| Mudlogging                                     |       |                  |           |
| Fishing, Milling and P&A Services              |       |                  |           |
| <b>Fields (grouped)</b>                        |       |                  |           |
| Construction                                   |       |                  |           |
| Drilling Fluids & Mud Engineering              |       |                  |           |
| Drilling Waste Management (Opt)                |       |                  |           |
| Other Major Services (Opt)                     |       |                  |           |
| <b>Wellhead Equipment &amp; Services</b>       |       |                  |           |
| Casing and Tubular Running Services            |       |                  |           |
| Casing & Liner                                 |       |                  |           |
| Tubulars (Conventional)                        |       |                  |           |
| Tubulars (RDM)                                 |       |                  |           |
| RDV Services                                   |       |                  |           |
| <b>Logistics</b>                               |       |                  |           |
| Helicopter                                     |       |                  |           |
| Standby Vessel                                 |       |                  |           |
| Supply Vessel                                  |       |                  |           |
| Anchor Handling Vessel / Pre-laying of anchors |       |                  |           |
| Logistics (base)                               |       |                  |           |
| <b>RDM upgrade cost</b>                        |       |                  |           |

|  | Conventional | RDM  |
|--|--------------|------|
| Mobilize and anchoring rig time (days)         | 3            | 3    |
| Test BOP (days)                                | 4            | 4    |
| Run BOP (days)                                 | 3            | 3    |
| Total drilling time (days)                     | 16           | 13.5 |
| Total run and cement casing/liner (days)       | 6            | 3    |
| Total wireline logging time                    | 7            | 7    |
| Plug and abandon (days)                        | 7            | 7    |
| Full BOP (days)                                | 2            | 2    |
| Well Completion (days)                         | 0            | 0    |
| Dry Hole and Rig Mobilization, Anchoring & P&A | 35           | 28.5 |
| Total dry time (days)                          | 47           | 40.5 |
| Total length casing + liner                    | 8100         | 8900 |
| Total depth drilled                            | 2300         | 2300 |
| User defined parameter                         |              |      |

|                  | Conventional | RDM   |
|------------------|--------------|-------|
| Rig Move and Mob | 120 %        | 120 % |
| Dry Hole         | 125 %        | 115 % |
| P&A and Demob    | 120 %        | 115 % |

|                  | Conventional | RDM   |
|------------------|--------------|-------|
| Rig Move and Mob | 120 %        | 120 % |
| Dry Hole         | 125 %        | 115 % |
| P&A and Demob    | 120 %        | 115 % |

Figure D2.2c – Input: Fixed costs and rates



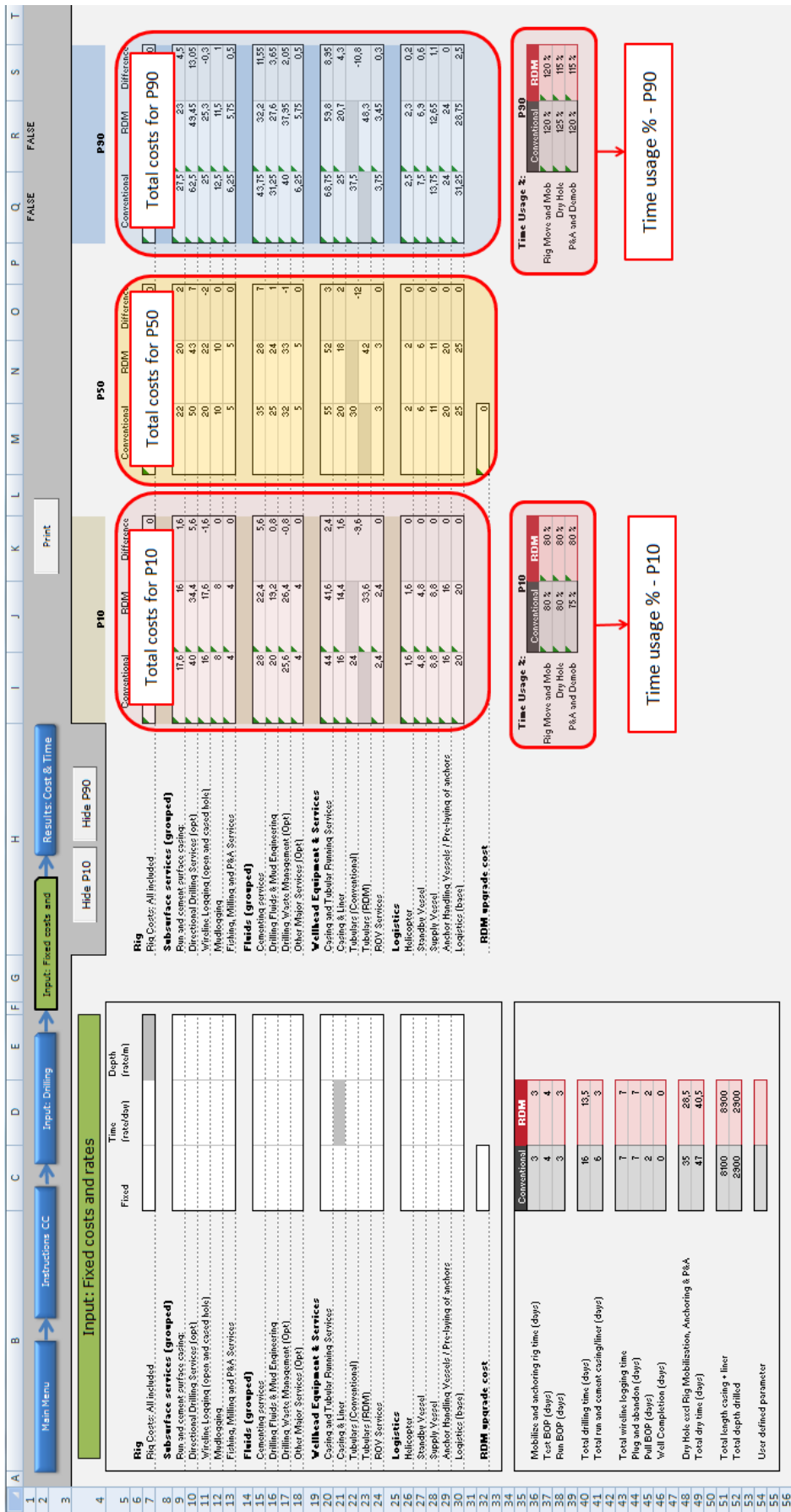


Figure D2.2d - Input: Fixed costs and rates

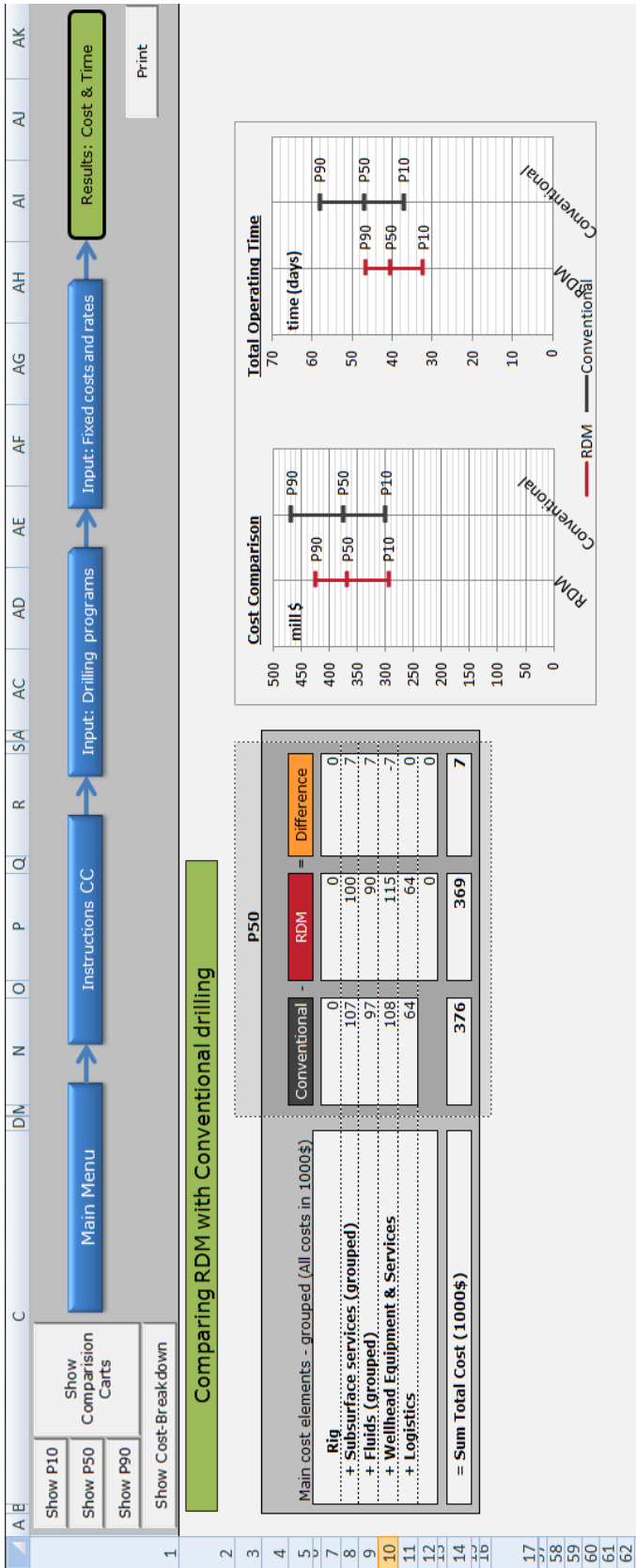


Figure D2.3a – Results: Cost & Time

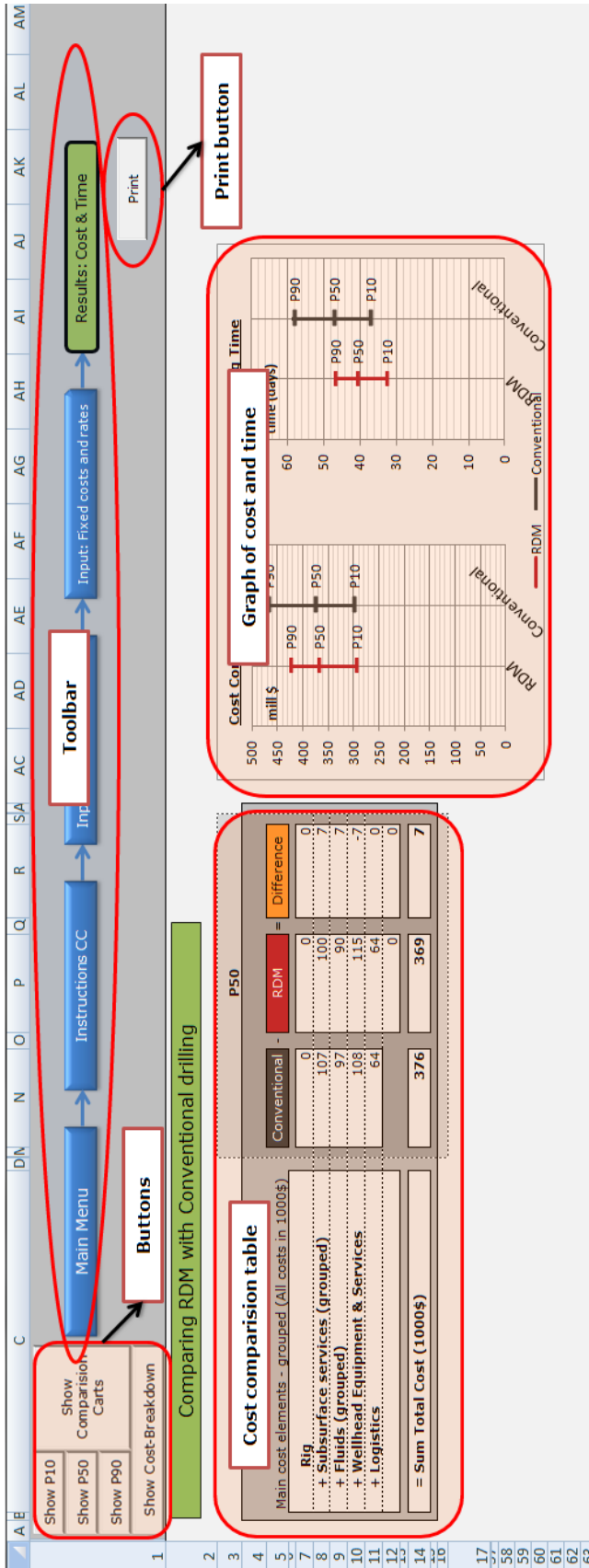


Figure D2.3b – Results: Cost & Time

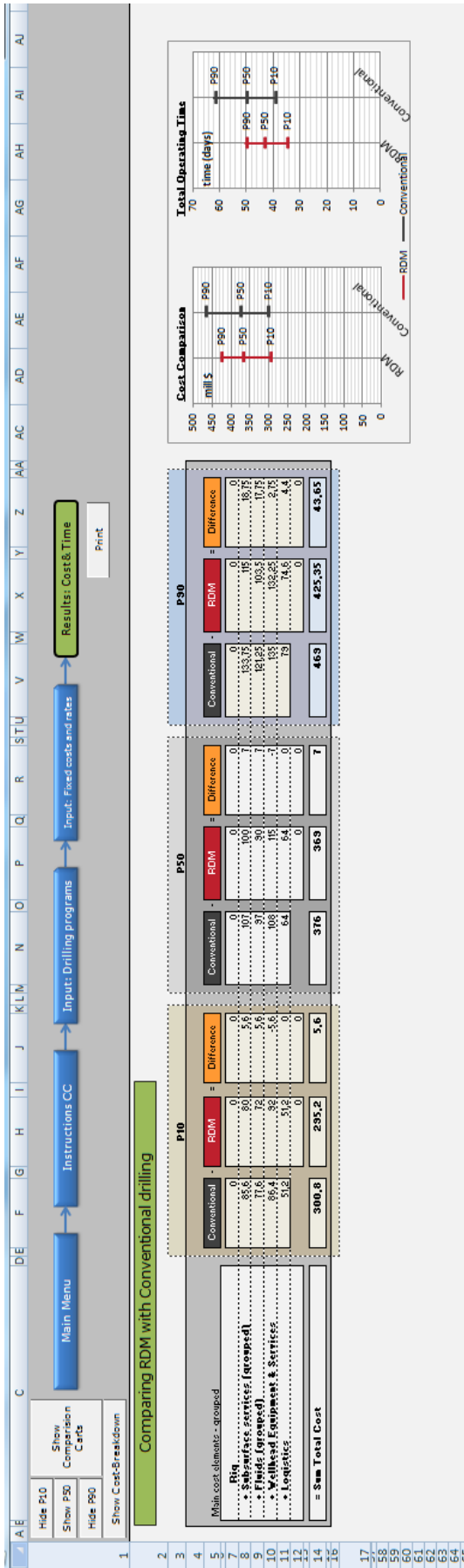


Figure D2.3c – Results: Cost & Time expanded to show P10 and P90.



Figure D2.3d – Results: Cost & Time expanded to show the cost-breakdown.

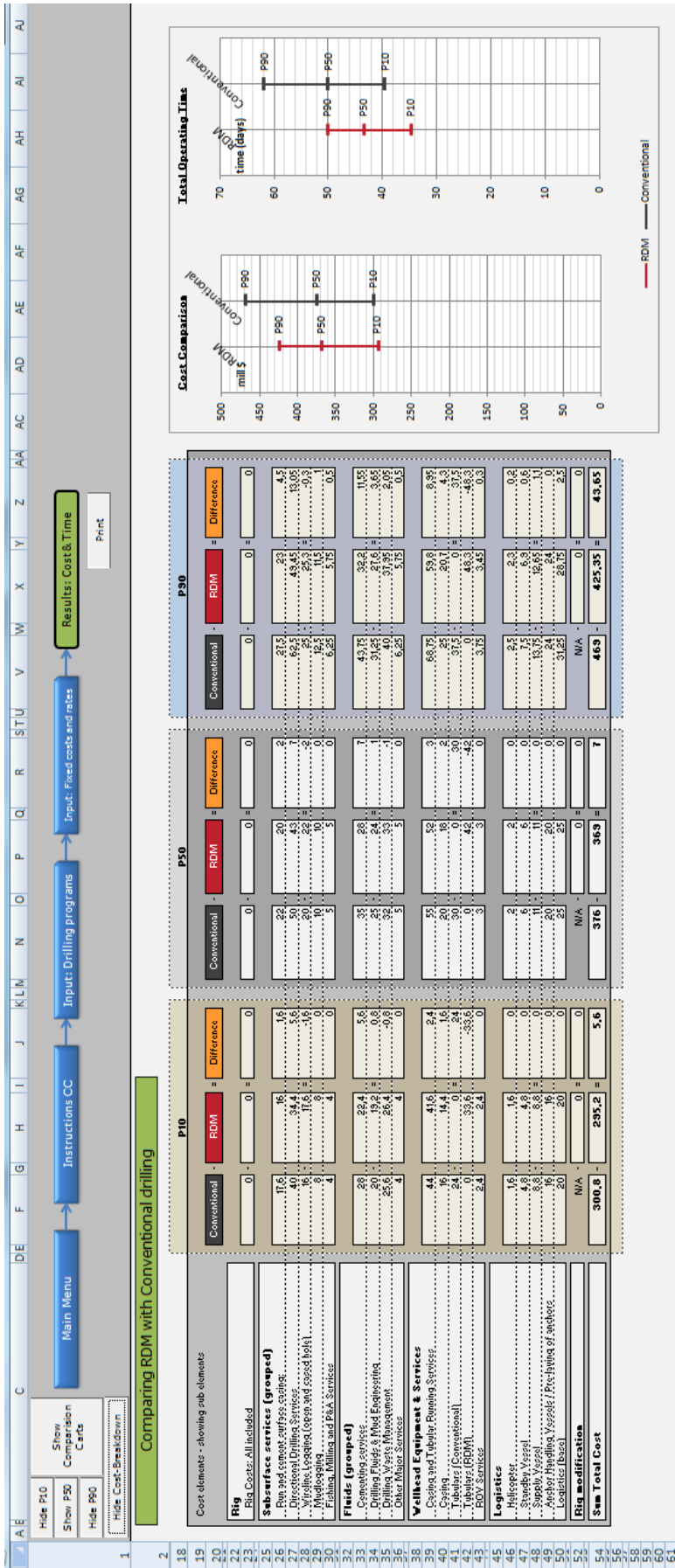


Figure D2.3e – Results: Cost & Time expanded to show both P10 and P90, and cost-breakdown

|    | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T |
|----|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 2  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 3  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 4  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 5  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 6  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 7  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 8  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 9  |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 10 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 11 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 12 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 13 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 14 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 15 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 16 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 17 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 18 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 19 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 20 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 21 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 22 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 23 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 24 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 25 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 26 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 27 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 28 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 29 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 30 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 31 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 32 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 33 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 34 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |
| 35 |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |   |

**Main Menu** → **Instructions FDA** → **Input: Key variables** → **Input: Estimate cost** → **Input: Production profiles** → **Input: Cash flows** → **Results: NPV**

**Print**

### Extended Reach Drilling (RDM) versus Subsea installation

**Case study:** Comparison of the added value when comparing the investment option an extended reach well from a platform (RDM) with a Subsea installation.

**Assumptions:**

**Step 1):** Enter the key variables in sheet "Input: Key variables". Choose the preferred system of measurement (metric or US customary units<sup>9</sup>, volume unit (barrel or 1000 Sm<sup>3</sup>) and enter the oil and gas prices. Oil and gas prices can be modelled as static or variable.

**Step 2):** Enter the high-level cost estimates of each activity in the two investment options in sheet "Input: Estimate cost".

**Step 3):** In sheet "Production profile" access sheet "Input: Production profiles".

**Step 4):** Enter up to three production profiles in the sheet "Input: Production profiles". Enter the base profile of the field and enter the added and lost production of each investment option.

**Step 5):** Access sheet "Production profile" and activate one of the three active sheets. All further calculations made by the model will use the active profile. It is recommended that the three profiles be used for P10, P50 and P90. If different oil and gas fields are to be used it is advisable to create a new model.

**Step 6):** Access sheet: "Input: Cash flows" and enter the following information:

- a) The operation and transportation cost when not investing, when using RDM and when using Subsea.
- b) The investment cost when using RDM or subsea. This investment cost should be the same as the one in sheet "Input: Estimate cost". The investment costs must be manually entered in order to account for the possibility to choose which year the investment is made.
- c) Depreciation and uplift if the Norwegian tax system was chosen.

**Step 7):** Output is the NPV of the investment options RDM and subsea. The added production of each option is also shown. The graph of the added and total productions can be changed in sheet "ProdGraph" (accessed from the output sheet).

Figure D3.1a – Instructions FDA.

The screenshot shows an Excel spreadsheet with columns A through T and rows 1 through 37. A blue navigation toolbar is located at the top, containing buttons for 'Main Menu', 'Instructions FDA', 'Input: Key variables', 'Input: Production profiles', 'Input: Cash flows', and 'Results: NPV'. A red oval highlights the 'Main Menu', 'Instructions FDA', and 'Results: NPV' buttons. A red box labeled 'Print button' points to the 'Print' button in the 'Results: NPV' section.

The main content area contains instructional text for 'Extended Reach Drilling (RDM) versus Subsea installation'. A red box labeled 'Explanation, instructions and step-by-step' highlights the 'Step 1' through 'Step 7' instructions.

**Extended Reach Drilling (RDM) versus Subsea installation**

**Case study:** Comparison of the added value when comparing the investment option an extended reach well from a platform (RDM) with a Subsea installation.

**Assumptions:**

**Step 1):** Enter the key variables in sheet "variables". Choose the preferred system of (metric or US customary units, volume unit (b Sm3) and enter the oil and gas prices. Oil and gas be modelled as static or variable.

**Step 2):** Enter the high-level cost estimates of each activity in the two investment options in sheet "Input: Estimate cost".

**Step 3):** In sheet "Production profile" access sheet "Input: Production profiles".

**Step 4):** Enter up to three production profiles in the sheet "Input: Production profiles". Enter the base profile of the field and enter the added and lost production of each investment option.

**Step 5):** Access sheet "Production profile" and activate one of the three active sheets. All further calculations made by the model will use the active profile. It is recommended that the three profiles be used for P10, P50 and P90. If different oil and gas fields are to be used it is advisable to create a new model.

**Step 6):** Access sheet: "Input: Cash flows" and enter the operation and transportation cost when investing, when using RDM and when using Subsea.

**Step 7):** Output is the NPV of the investment options RDM and subsea. The added production of each option is also shown. The graph of the added and total productions can be changed in sheet "ProdGraph" (accessed from the output sheet).

Figure D3.1b – Instructions FDA.



|    | A | B | C   | D                 | E                    | F                    | G                 | H                 | I            | J | Q | R | S | T | U | V | W | X     |  |
|----|---|---|---|-------------------|----------------------|----------------------|-------------------|-------------------|--------------|---|---|---|---|---|---|---|---|-------|--|
| 1  |   |   | Main Menu   | Instructions: FDA | Input: Key variables | Input: Estimate cost | Input: Production | Input: Cash flows | Results: NPV |   |   |   |   |   |   |   |   | Print |  |
| 2  |   |   | <b>Input: Key variables</b>                                   |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 3  |   |   | <b>System of measurement</b>                                  |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 4  |   |   | Select your preferred system of measurements:                 |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 5  |   |   | <input type="radio"/> Metric (1000 sm <sup>3</sup> )          |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 6  |   |   | <input checked="" type="radio"/> US customary units (barrels) |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 7  |   |   |   |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 8  |   |   |   |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 9  |   |   |   |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 10 |   |   |   |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 11 |   |   |   |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 12 |   |   |   |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 13 |   |   |   |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 14 |   |   |   |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 15 |   |   | <b>Petroleum prices options</b>                               |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 16 |   |   | <input checked="" type="radio"/> Use Rigid Prices             |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 17 |   |   | <input type="radio"/> Use Variable Prices                     |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 18 |   |   | Oil Price (USD/bbl) \$ 120,00                                 |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 19 |   |   | Gas Price (USD/bbl) \$ 9,00                                   |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 20 |   |   | NGL Price (USD/bbl) \$ 55,00                                  |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 21 |   |   | Condensate Price (USD/bbl) \$ 66,00                           |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 22 |   |   | <b>Discount rates for different Cash Flows</b>                |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 23 |   |   | Discount rate: RDM 5,0 %                                      |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 24 |   |   | Discount rate: Subsea 5,0 %                                   |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
| 25 |   |   | <b>Tax Options</b>  |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
|    |   |   | <input type="radio"/> Use effective tax rate percent          |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
|    |   |   | Effective tax rate: 78 %                                      |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
|    |   |   | <input checked="" type="radio"/> Use Norwegian tax system     |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |
|    |   |   | <a href="#">Read more in FAQ.</a>                             |                   |                      |                      |                   |                   |              |   |   |   |   |   |   |   |   |       |  |

Figure D3.2a – Input: Key variables.

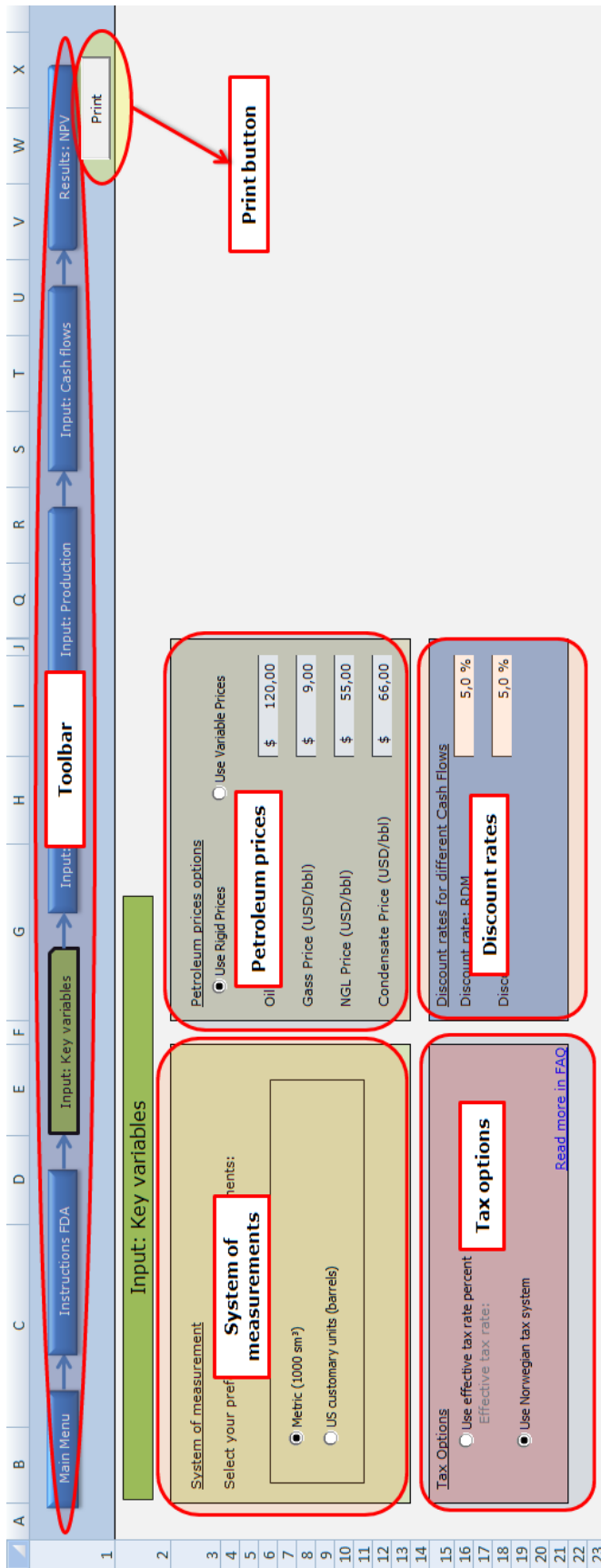


Figure D3.2b – Input: Key variables.

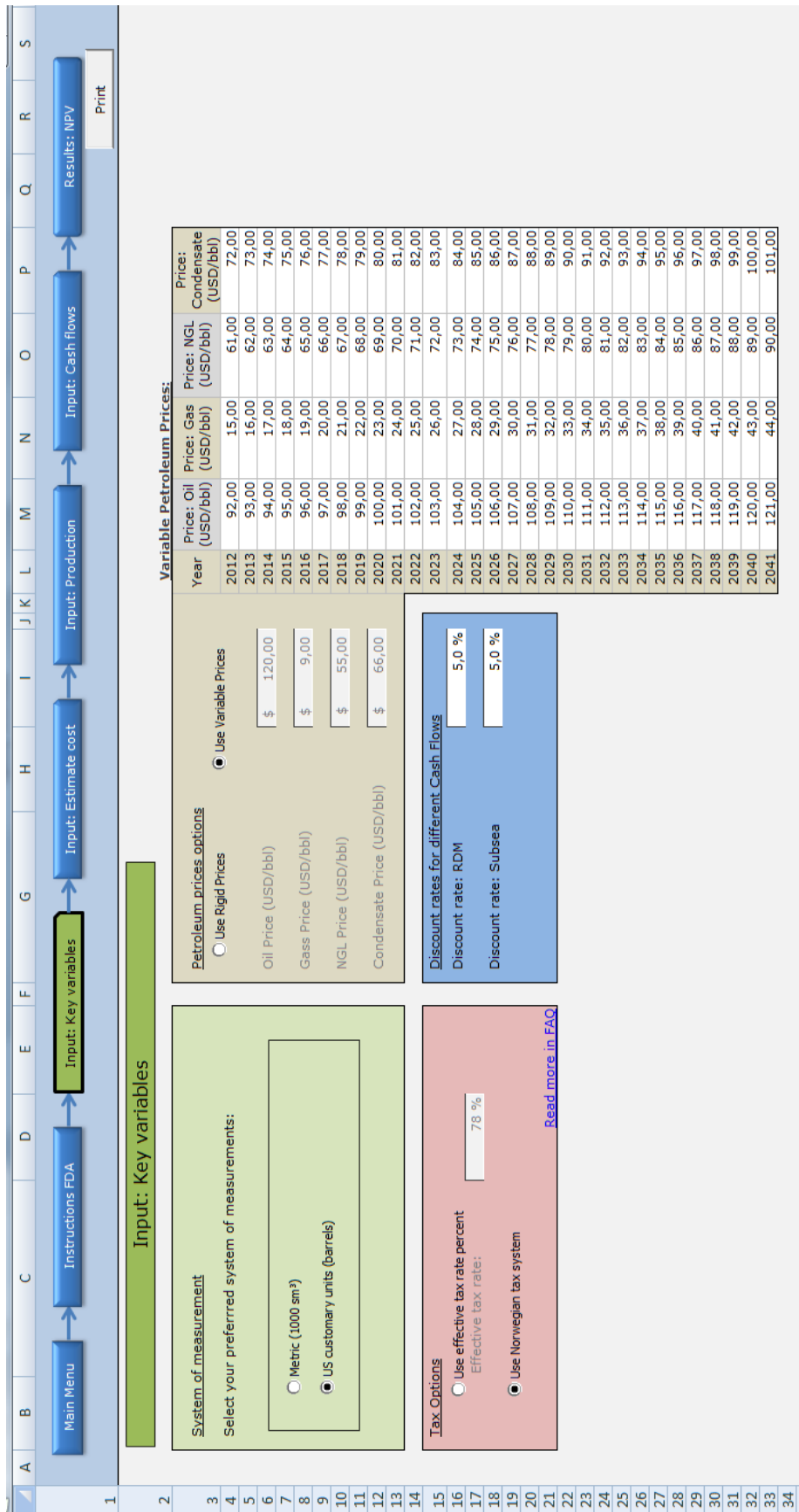


Figure D3.2c – *Input: Key variables* expanded to show a table of yearly dynamic petroleum prices.

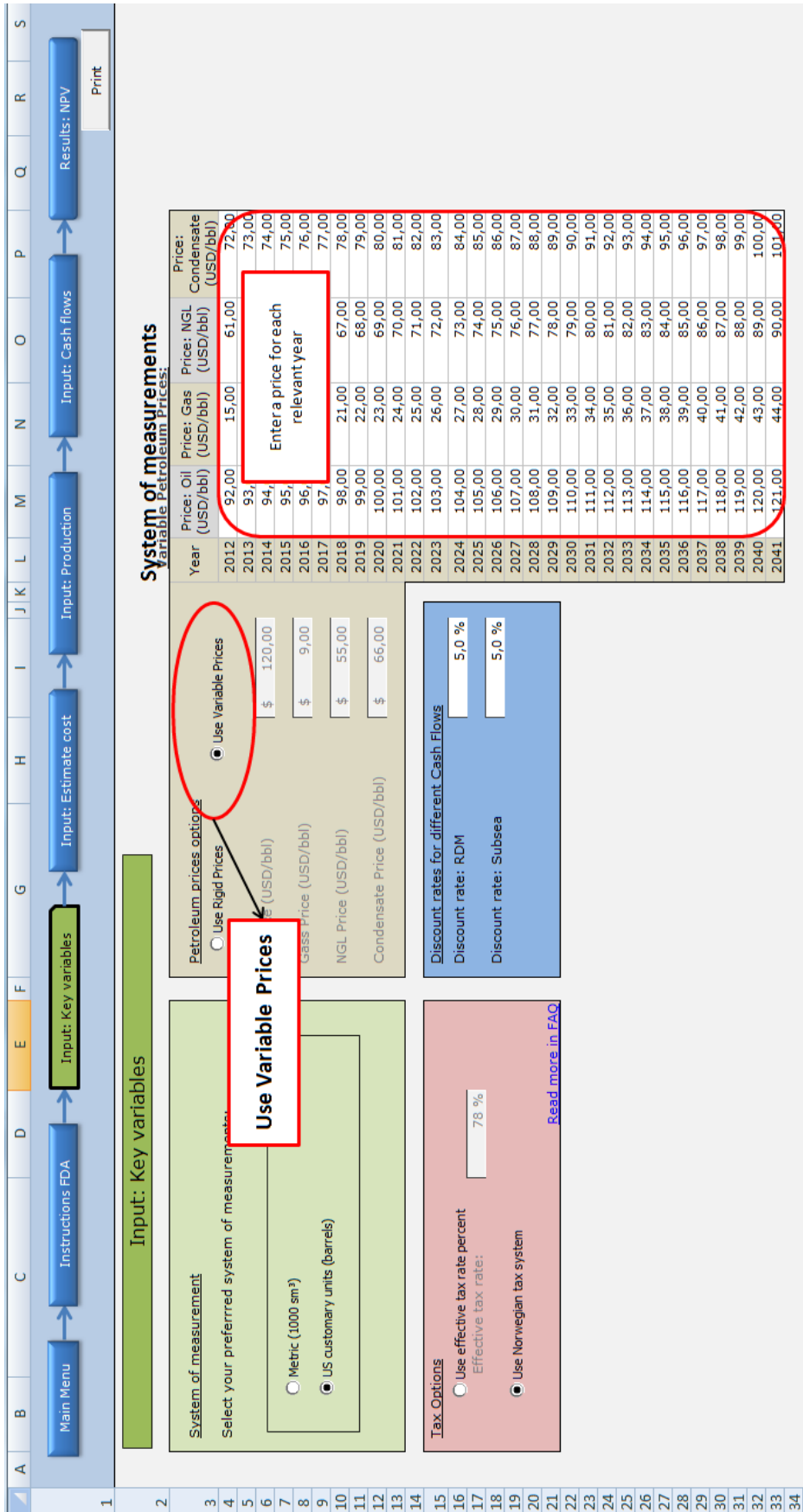


Figure D3.2d – Input: Key variables expanded to show a table of yearly dynamic petroleum prices.

Navigation: A B C D E F I J M O R U V W X Z AA AB AC AF AI/AK AN AO AS

Main Menu → Instructions FDA → Input: Key variables → Input: Estimate cost → Input: Production profiles → Input: Cashflows → Results: NPV

Use Sum From Cost-Breakdown [Show Cost-Breakdown](#) [Print](#)

**Input: Estimate investment cost**

| RDM                        |  | Rate/day (1000 \$) | Days P50 | Sum P50       |
|----------------------------|--|--------------------|----------|---------------|
| Rig cost                   |  | 100                | 165      | 16 500        |
| Spread cost                |  | 400                | 150      | 60 000        |
| Completion                 |  | 5000               |          | 5 000         |
| RDM upgrade cost           |  | 1000               |          | 1 000         |
| <b>Sum (whole 1000 \$)</b> |  |                    |          | <b>82 500</b> |

| Subsea                   |  | Rate/day | Days P50 | Sum P50        |
|--------------------------|--|----------|----------|----------------|
| Rig cost                 |  | 500      | 75       | 37 500         |
| Spread cost              |  | 400      | 60       | 24 000         |
| Completion               |  | 5000     |          | 5 000          |
| Subsea Production System |  | 133300   | 1        | 133300         |
| <b>Sum</b>               |  |          |          | <b>199 800</b> |

Figure D3.3a – Input: Estimate cost.

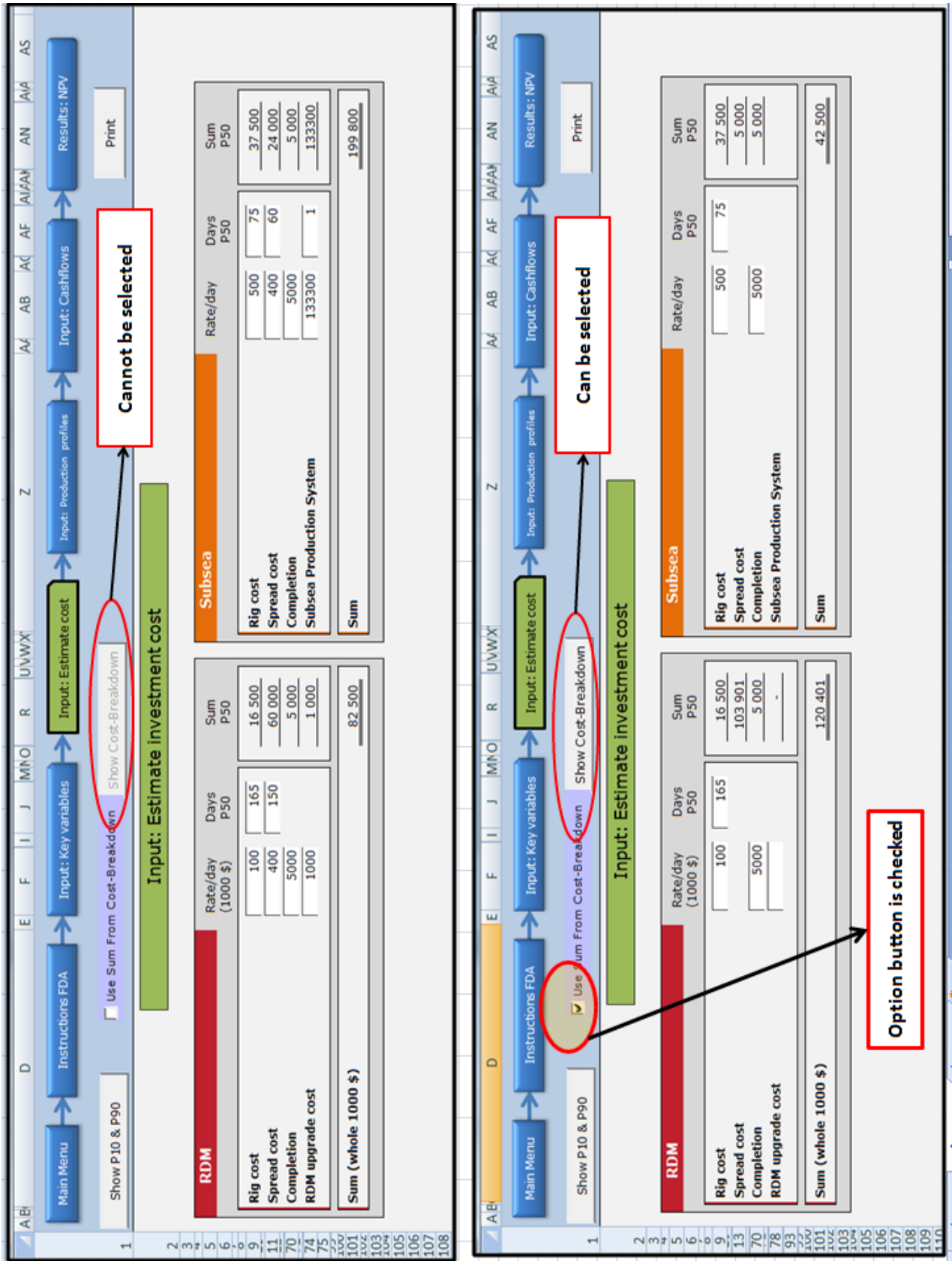


Figure D3.3b – *Input: Estimate cost*. In order to use the more detailed “cost-breakdown” you must check the option button.

→  →  →  →  →  →

Use Sum From Cost-Breakdown

**Input: Estimate investment cost**

|  | Rate/Day<br>(1000 \$) | Days<br>P50 | Sum<br>P50 |
|--|-----------------------|-------------|------------|
| <b>RDM</b>                               |                       |             |            |
| <b>Rig cost</b>                          | 100                   | 165         | 16,500     |
| <b>Spread cost</b>                       |                       |             | 102,901    |
| <b>Subsurface services</b>               |                       |             | P50        |
| Directional Drilling Services            |                       |             | -          |
| Wireline Logging (open and case hole)    | 999                   | 99          | 99,901     |
| Mudlogging                               |                       |             | -          |
| Fishing, Milling and P&A Services        |                       |             | -          |
| <b>Fluids</b>                            |                       |             | P50        |
| Cementing services                       |                       |             | -          |
| Drilling Fluids & Mud Engineering        |                       |             | -          |
| Drilling Waste Management                |                       |             | -          |
| Other Major Services                     |                       |             | -          |
| <b>Wellhead Equipment &amp; Services</b> |                       |             | P50        |
| Coring and Tubular Running Services      |                       |             | -          |
| Coring                                   |                       |             | -          |
| Tubulars (RDM)                           |                       |             | -          |
| ROV Services                             |                       |             | -          |
| <b>Logistics</b>                         |                       |             | P50        |
| Helicopter                               |                       |             | -          |
| Standby Vessel                           |                       |             | -          |
| Supply Vessel                            |                       |             | -          |
| Anchor Handling Tugs and Barge (AHTS)    |                       |             | -          |
| Logistics (base)                         |                       |             | -          |
| <b>Completion</b>                        | 5000                  |             | 5,000      |
| <b>RDM upgrade cost</b>                  |                       |             | -          |
| <b>Sum (total: 1000 \$)</b>              |                       |             | 120,401    |

|  | Rate/Day<br>P50 | Days<br>P50 | Sum<br>P50 |
|--|-----------------|-------------|------------|
| <b>Subsea</b>                            |                 |             |            |
| <b>Rig cost</b>                          | 500             | 75          | 37,500     |
| <b>Spread cost</b>                       |                 |             | 5,000      |
| <b>Subsurface services</b>               |                 |             | P50        |
| Directional Drilling Services            |                 |             | -          |
| Wireline Logging (open and case hole)    |                 |             | -          |
| Mudlogging                               |                 |             | -          |
| Fishing, Milling and P&A Services        |                 |             | -          |
| <b>Fluids</b>                            |                 |             | P50        |
| Cementing services                       |                 |             | -          |
| Drilling Fluids & Mud Engineering        |                 |             | -          |
| Drilling Waste Management                |                 |             | -          |
| Other Major Services                     |                 |             | -          |
| <b>Wellhead Equipment &amp; Services</b> |                 |             | P50        |
| Coring and Tubular Running Services      |                 |             | -          |
| Coring                                   |                 |             | -          |
| Tubulars (RDM)                           |                 |             | -          |
| ROV Services                             |                 |             | -          |
| <b>Logistics</b>                         |                 |             | P50        |
| Helicopter                               |                 |             | -          |
| Standby Vessel                           |                 |             | -          |
| Supply Vessel                            |                 |             | -          |
| Anchor Handling Tugs and Barge (AHTS)    |                 |             | -          |
| Logistics (base)                         |                 |             | -          |
| <b>Completion</b>                        | 5000            |             | 5,000      |
| <b>Subsea Production System</b>          |                 |             | -          |
| Christmas tree                           |                 |             | -          |
| Control System                           |                 |             | -          |
| Structure / Template                     |                 |             | -          |
| Installation                             |                 |             | -          |
| Flareline & Umbilical                    |                 |             | -          |
| <b>Sum</b>                               |                 |             | 42,500     |

Figure D3.3c – Input: Estimate cost with option for cost-breakdown enabled.



Figure D3.3d – Input: Estimate cost showing P10 and P90 cost values.



The screenshot displays a spreadsheet interface with a menu for 'Input: Production profiles'. The menu is organized as follows:

- Top Row (152):** Buttons for 'Main Menu', 'Instructions FDA', 'Input: Key variables', 'Input: Estimate cost', 'Input: Production profiles', 'Input: Cash flows', and 'Results: NPV'.
- Second Row (153):** A sub-menu for 'Input: Production profiles' is open, containing:
  - Buttons: 'Load Base Profile', 'Reset Profiles', 'Link forecasts to P50', 'Show Production Chart'.
  - Text: 'Imported base profile: Snorre', 'Data format: 1000 barrels', 'Start year (YYYY):'.
  - Buttons: 'Show P10', 'Show P50', 'Show P90'.
  - Text: 'Go to production profile for P10', 'Go to production profile for P50', 'Go to production profile for P90'.
  - Text: 'Total reservoir size (1000 bbl) 10000', 'Choose input data:'. Below this are checkboxes for 'Oil', 'Gas', 'NGL', and 'Condensate'.
- Bottom Row (183):** Row numbers 152 through 183 are listed on the left side of the spreadsheet.

Figure D3.4a – The sheet menu for *Input: Production profiles*.

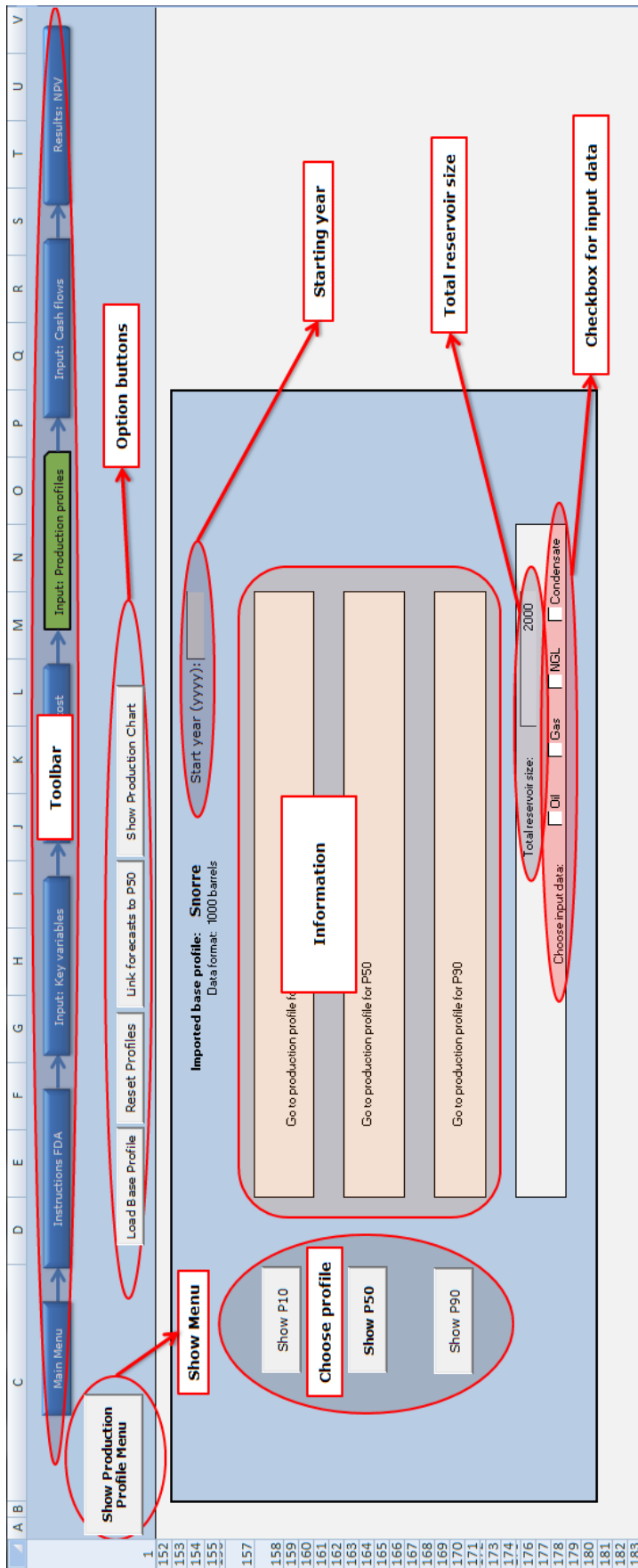


Figure D3.4b - The sheet menu for *Input: Production profiles*.

|    | A  | B      | C      | D      | E      | F      | G      | H      | I      | J      | K      | L      | M      | N      | O      | P      | Q      | R      | S      | T    | U | V |
|----|--|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|--------|------|---|---|
| 1  | <div style="display: flex; justify-content: space-between; align-items: center;"> <div style="text-align: center;"> <p>Instructions FDA</p> <p>Input: Key variables</p> <p>Input: Estimate cost</p> <p>Input: Production profiles</p> <p>Input: Cash flows</p> <p>Results: NPV</p> </div> <div style="text-align: center;"> <p>Load Base Profile</p> <p>Reset Profiles</p> <p>Link forecasts to P50</p> <p>Show Production Chart</p> </div> </div> |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |      |   |   |
| 2  | P50  |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |      |   |   |
| 3  | P50  |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |      |   |   |
| 4  | Time: Years  | 1992   | 1993   | 1994   | 1995   | 1996   | 1997   | 1998   | 1999   | 2000   | 2001   | 2002   | 2003   | 2004   | 2005   | 2006   | 2007   | 2008   | 2009   | 2010 |   |   |
| 5  | Base profile, Oil  | 9799,7 | 43455  | 62092  | 71542  | 72219  | 67742  | 63471  | 59116  | 54013  | 72617  | 79506  | 85530  | 72577  | 56330  | 52301  | 52719  | 53286  | 41020  | 364  |   |   |
| 6  | Base profile, Gas  | 0      | 1354,6 | 2854,1 | 3946,7 | 3842,8 | 3630,8 | 2875,3 | 1938,9 | 1839,7 | 3273,9 | 2827,5 | 2553,3 | 1211,6 | 2154,9 | 922,37 | 404,58 | 1440,5 | 877,02 | 864, |   |   |
| 7  | Base profile, NGL  | 545,69 | 3116,2 | 3839,7 | 4274,9 | 3948,8 | 3573,6 | 3867,2 | 3506,3 | 3364,9 | 6134   | 5890,2 | 4193,1 | 1646,9 | 2545,1 | 1386,2 | 530,46 | 1153,9 | 599,89 | 597, |   |   |
| 8  | Base profile, Condensate   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0    |   |   |
| 9  | Added production, Oil  | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0    |   |   |
| 10 | Added production, Gas  | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0    |   |   |
| 11 | Added production, NGL  | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0    |   |   |
| 12 | Added production, Condensate   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0    |   |   |
| 13 | Lost Production, Oil   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0    |   |   |
| 14 | Lost Production, Gas   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0    |   |   |
| 15 | Lost Production, NGL   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0    |   |   |
| 16 | Lost Production, Condensate  | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0    |   |   |
| 17 | Input: Added Production, Oil   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0    |   |   |
| 18 | Input: Added Production, Gas   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0    |   |   |
| 19 | Input: Added Production, NGL   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0    |   |   |
| 20 | Input: Added Production, Condensate  | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0    |   |   |
| 21 | Input: Lost Production, Oil  | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0    |   |   |
| 22 | Input: Lost Production, Gas  | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0    |   |   |
| 23 | Input: Lost Production, NGL  | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0    |   |   |
| 24 | Input: Lost Production, Condensate   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0    |   |   |
| 25 |  |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |      |   |   |
| 26 |  |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |        |      |   |   |
| 27 | Total Production, Oil  | 9799,7 | 43455  | 62092  | 71542  | 72219  | 67742  | 63471  | 59116  | 54013  | 72617  | 79506  | 85530  | 72577  | 56330  | 52301  | 52719  | 53286  | 41020  | 364  |   |   |
| 28 | Total Production, Gas  | 0      | 1354,6 | 2854,1 | 3946,7 | 3842,8 | 3630,8 | 2875,3 | 1938,9 | 1839,7 | 3273,9 | 2827,5 | 2553,3 | 1211,6 | 2154,9 | 922,37 | 404,58 | 1440,5 | 877,02 | 864, |   |   |
| 29 | Total Production, NGL  | 545,69 | 3116,2 | 3839,7 | 4274,9 | 3948,8 | 3573,6 | 3867,2 | 3506,3 | 3364,9 | 6134   | 5890,2 | 4193,1 | 1646,9 | 2545,1 | 1386,2 | 530,46 | 1153,9 | 599,89 | 597, |   |   |
| 30 | Total Production, Condensate   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0    |   |   |
| 31 | Total Production, Oil  | 9799,7 | 43455  | 62092  | 71542  | 72219  | 67742  | 63471  | 59116  | 54013  | 72617  | 79506  | 85530  | 72577  | 56330  | 52301  | 52719  | 53286  | 41020  | 364  |   |   |
| 32 | Total Production, Gas  | 0      | 1354,6 | 2854,1 | 3946,7 | 3842,8 | 3630,8 | 2875,3 | 1938,9 | 1839,7 | 3273,9 | 2827,5 | 2553,3 | 1211,6 | 2154,9 | 922,37 | 404,58 | 1440,5 | 877,02 | 864, |   |   |
| 33 | Total Production, NGL  | 545,69 | 3116,2 | 3839,7 | 4274,9 | 3948,8 | 3573,6 | 3867,2 | 3506,3 | 3364,9 | 6134   | 5890,2 | 4193,1 | 1646,9 | 2545,1 | 1386,2 | 530,46 | 1153,9 | 599,89 | 597, |   |   |
| 34 | Total Production, Condensate   | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0      | 0    |   |   |

Figure D3.4c - Input: Production profiles showing a production profile for P50 scenario.

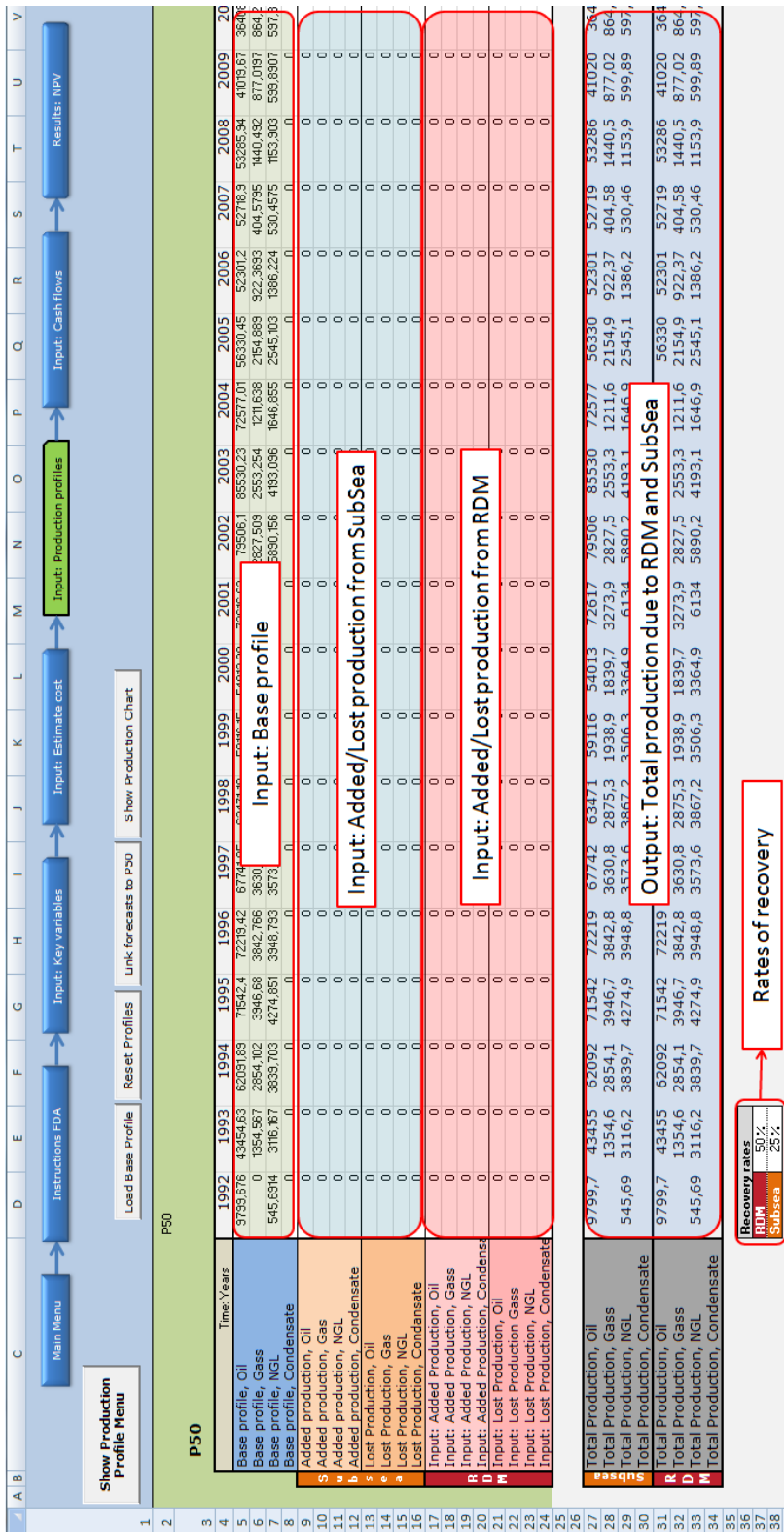


Figure D3.4d - Input: Production profiles showing a production profile for P50 scenario.

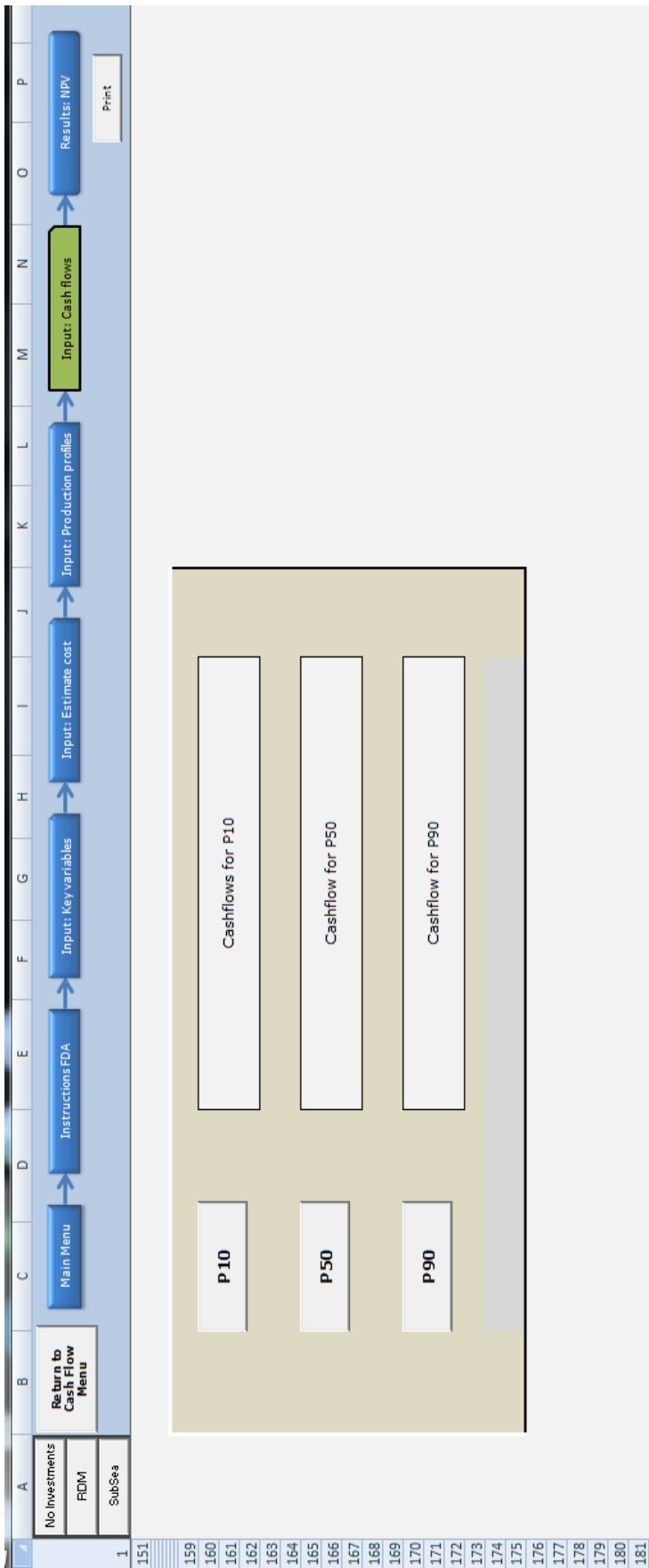


Figure D3.5a - The sheet menu for *Input: Cash flows*.

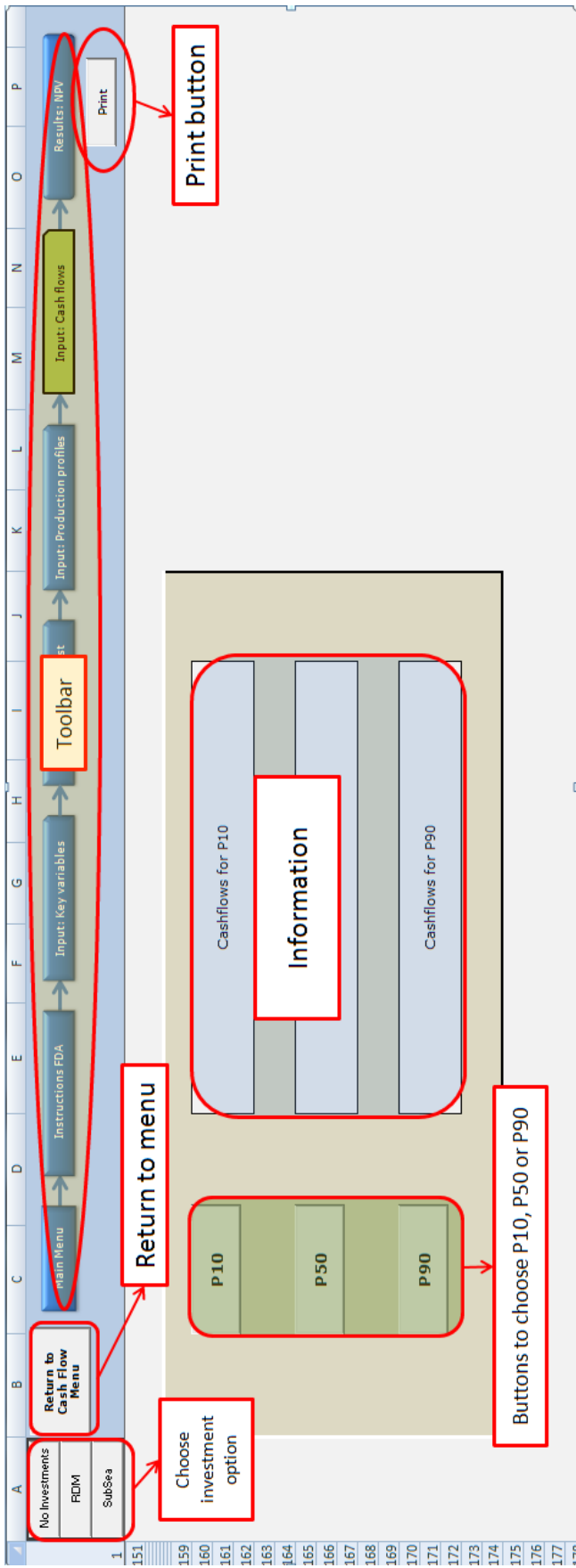


Figure D3.5b - The sheet menu for *Input: Cash flows*.

| Year | Produced Oil (1000 barrels) | Produced Gas (1000 barrels) | Produced NGL (1000 barrels) | Produced condensate (1000 barrels) | Price: Oil (\$/barrel) | Price: Gas (\$/barrel) | Price: NGL (\$/barrel) | Price: Condensate (\$/barrel) | Revenue (10000\$) | Operation Cost (10000\$) | Transport Cost (10000\$) | Investment cost (10000\$) | Other Costs (10000\$) | Depreciation (10000\$) | Uplift (10000\$) | Tax (Norway) (10000\$) | Discretionary cash flow (10000\$) |
|------|-----------------------------|-----------------------------|-----------------------------|------------------------------------|------------------------|------------------------|------------------------|-------------------------------|-------------------|--------------------------|--------------------------|---------------------------|-----------------------|------------------------|------------------|------------------------|-----------------------------------|
| 4    | 32 800                      | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | 3 936 000         | 85 000                   | 5 000                    | -                         | -                     | -                      | -                | 2 999 880              | 846 120                           |
| 5    | 31 000                      | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | 3 720 000         | 85 000                   | 5 000                    | -                         | -                     | -                      | -                | 2 831 400              | 796 600                           |
| 6    | 29 200                      | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | 3 504 000         | 85 000                   | 5 000                    | -                         | -                     | -                      | -                | 2 662 320              | 751 080                           |
| 7    | 27 400                      | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | 3 288 000         | 85 000                   | 5 000                    | -                         | -                     | -                      | -                | 2 494 440              | 703 560                           |
| 8    | 25 600                      | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | 3 072 000         | 85 000                   | 5 000                    | -                         | -                     | -                      | -                | 2 325 960              | 656 040                           |
| 9    | 23 800                      | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | 2 856 000         | 85 000                   | 5 000                    | -                         | -                     | -                      | -                | 2 157 480              | 608 520                           |
| 10   | 22 000                      | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | 2 640 000         | 85 000                   | 5 000                    | -                         | -                     | -                      | -                | 1 989 000              | 561 000                           |
| 11   | 21 000                      | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | 2 520 000         | 85 000                   | 5 000                    | -                         | -                     | -                      | -                | 1 895 400              | 534 600                           |
| 12   | 21 000                      | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | 2 520 000         | 85 000                   | 5 000                    | -                         | -                     | -                      | -                | 1 895 400              | 534 600                           |
| 13   | 21 000                      | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | 2 520 000         | 85 000                   | 5 000                    | -                         | -                     | -                      | -                | 1 895 400              | 534 600                           |
| 14   | 20 000                      | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | 2 400 000         | 85 000                   | 5 000                    | -                         | -                     | -                      | -                | 1 801 800              | 508 200                           |
| 15   | 20 000                      | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | 2 400 000         | 85 000                   | 5 000                    | -                         | -                     | -                      | -                | 1 801 800              | 508 200                           |
| 16   | 20 000                      | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | 2 400 000         | 85 000                   | 5 000                    | -                         | -                     | -                      | -                | 1 801 800              | 508 200                           |
| 17   | 18 000                      | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | 2 160 000         | 85 000                   | 5 000                    | -                         | -                     | -                      | -                | 1 614 600              | 455 400                           |
| 18   | 18 000                      | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | 2 160 000         | 85 000                   | 5 000                    | -                         | -                     | -                      | -                | 1 614 600              | 455 400                           |
| 19   | 18 000                      | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | 2 160 000         | 85 000                   | 5 000                    | -                         | -                     | -                      | -                | 1 614 600              | 455 400                           |
| 20   | 16 000                      | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | 1 920 000         | 85 000                   | 5 000                    | -                         | -                     | -                      | -                | 1 427 400              | 402 600                           |
| 21   | 16 000                      | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | 1 920 000         | 85 000                   | 5 000                    | -                         | -                     | -                      | -                | 1 427 400              | 402 600                           |
| 22   | 16 000                      | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | 1 920 000         | 85 000                   | 5 000                    | -                         | -                     | -                      | -                | 1 427 400              | 402 600                           |
| 23   | -                           | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | -                 | -                        | -                        | -                         | -                     | -                      | -                | -                      | -                                 |
| 24   | -                           | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | -                 | -                        | -                        | -                         | -                     | -                      | -                | -                      | -                                 |
| 25   | -                           | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | -                 | -                        | -                        | -                         | -                     | -                      | -                | -                      | -                                 |
| 26   | -                           | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | -                 | -                        | -                        | -                         | -                     | -                      | -                | -                      | -                                 |
| 27   | -                           | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | -                 | -                        | -                        | -                         | -                     | -                      | -                | -                      | -                                 |
| 28   | -                           | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | -                 | -                        | -                        | -                         | -                     | -                      | -                | -                      | -                                 |
| 29   | -                           | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | -                 | -                        | -                        | -                         | -                     | -                      | -                | -                      | -                                 |
| 30   | -                           | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | -                 | -                        | -                        | -                         | -                     | -                      | -                | -                      | -                                 |
| 31   | -                           | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | -                 | -                        | -                        | -                         | -                     | -                      | -                | -                      | -                                 |
| 32   | -                           | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | -                 | -                        | -                        | -                         | -                     | -                      | -                | -                      | -                                 |
| 33   | -                           | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | -                 | -                        | -                        | -                         | -                     | -                      | -                | -                      | -                                 |
| 34   | -                           | -                           | -                           | -                                  | 120.00                 | 9.00                   | 55.00                  | 66.00                         | -                 | -                        | -                        | -                         | -                     | -                      | -                | -                      | -                                 |

Figure D3.5c - Input: Cash flows.

| Year | Produced Oil (1000 barrels) | Produced gas (1000 barrels) | Produced MGL (1000 barrels) | Produced condensate (1000 barrels) | Price: Oil (\$/barrel) | Price: Gas (\$/barrel) | Price: MGL (\$/barrel) | Price: Condensate (\$/barrel) | Revenue (1000\$) | Operation Cost (1000\$) | Transport Cost (1000\$) | Investment cost (1000\$) | Other Costs (1000\$) | Depreciation (1000\$) | Uplift (1000\$) | Tax (Norway) (1000\$) | Discretionary cash flow (1000\$) |
|------|-----------------------------|-----------------------------|-----------------------------|------------------------------------|------------------------|------------------------|------------------------|-------------------------------|------------------|-------------------------|-------------------------|--------------------------|----------------------|-----------------------|-----------------|-----------------------|----------------------------------|
| 2012 | 32800                       | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 3938000          | 85000                   | 5000                    | -                        | -                    | -                     | -               | 2395800               | 886000                           |
| 2013 | 31000                       | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 3938000          | 85000                   | 5000                    | -                        | -                    | -                     | -               | 2395800               | 886000                           |
| 2014 | 29200                       | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 3938000          | 85000                   | 5000                    | -                        | -                    | -                     | -               | 2395800               | 886000                           |
| 2015 | 27400                       | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 3938000          | 85000                   | 5000                    | -                        | -                    | -                     | -               | 2395800               | 886000                           |
| 2016 | 25600                       | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 3938000          | 85000                   | 5000                    | -                        | -                    | -                     | -               | 2395800               | 886000                           |
| 2017 | 23800                       | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 3938000          | 85000                   | 5000                    | -                        | -                    | -                     | -               | 2395800               | 886000                           |
| 2018 | 22000                       | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 3938000          | 85000                   | 5000                    | -                        | -                    | -                     | -               | 2395800               | 886000                           |
| 2019 | 21000                       | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 3938000          | 85000                   | 5000                    | -                        | -                    | -                     | -               | 2395800               | 886000                           |
| 2020 | 21000                       | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 3938000          | 85000                   | 5000                    | -                        | -                    | -                     | -               | 2395800               | 886000                           |
| 2021 | 20000                       | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 3938000          | 85000                   | 5000                    | -                        | -                    | -                     | -               | 2395800               | 886000                           |
| 2022 | 20000                       | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 3938000          | 85000                   | 5000                    | -                        | -                    | -                     | -               | 2395800               | 886000                           |
| 2023 | 20000                       | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 3938000          | 85000                   | 5000                    | -                        | -                    | -                     | -               | 2395800               | 886000                           |
| 2024 | 20000                       | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 3938000          | 85000                   | 5000                    | -                        | -                    | -                     | -               | 2395800               | 886000                           |
| 2025 | 18000                       | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 3938000          | 85000                   | 5000                    | -                        | -                    | -                     | -               | 2395800               | 886000                           |
| 2026 | 18000                       | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 3938000          | 85000                   | 5000                    | -                        | -                    | -                     | -               | 2395800               | 886000                           |
| 2027 | 18000                       | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 3938000          | 85000                   | 5000                    | -                        | -                    | -                     | -               | 2395800               | 886000                           |
| 2028 | 16000                       | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 3938000          | 85000                   | 5000                    | -                        | -                    | -                     | -               | 2395800               | 886000                           |
| 2029 | 16000                       | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 3938000          | 85000                   | 5000                    | -                        | -                    | -                     | -               | 2395800               | 886000                           |
| 2030 | 16000                       | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 3938000          | 85000                   | 5000                    | -                        | -                    | -                     | -               | 2395800               | 886000                           |
| 2031 | -                           | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 1920000          | -                       | -                       | -                        | -                    | -                     | -               | -                     | -                                |
| 2032 | -                           | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 1920000          | -                       | -                       | -                        | -                    | -                     | -               | -                     | -                                |
| 2033 | -                           | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 1920000          | -                       | -                       | -                        | -                    | -                     | -               | -                     | -                                |
| 2034 | -                           | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 1920000          | -                       | -                       | -                        | -                    | -                     | -               | -                     | -                                |
| 2035 | -                           | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 1920000          | -                       | -                       | -                        | -                    | -                     | -               | -                     | -                                |
| 2036 | -                           | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 1920000          | -                       | -                       | -                        | -                    | -                     | -               | -                     | -                                |
| 2037 | -                           | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 1920000          | -                       | -                       | -                        | -                    | -                     | -               | -                     | -                                |
| 2038 | -                           | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 1920000          | -                       | -                       | -                        | -                    | -                     | -               | -                     | -                                |
| 2039 | -                           | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 1920000          | -                       | -                       | -                        | -                    | -                     | -               | -                     | -                                |
| 2040 | -                           | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 1920000          | -                       | -                       | -                        | -                    | -                     | -               | -                     | -                                |
| 2041 | -                           | -                           | -                           | -                                  | 120.0                  | 9.00                   | 55.00                  | 66.00                         | 1920000          | -                       | -                       | -                        | -                    | -                     | -               | -                     | -                                |

Figure D3.5d - Input: Cash flows.



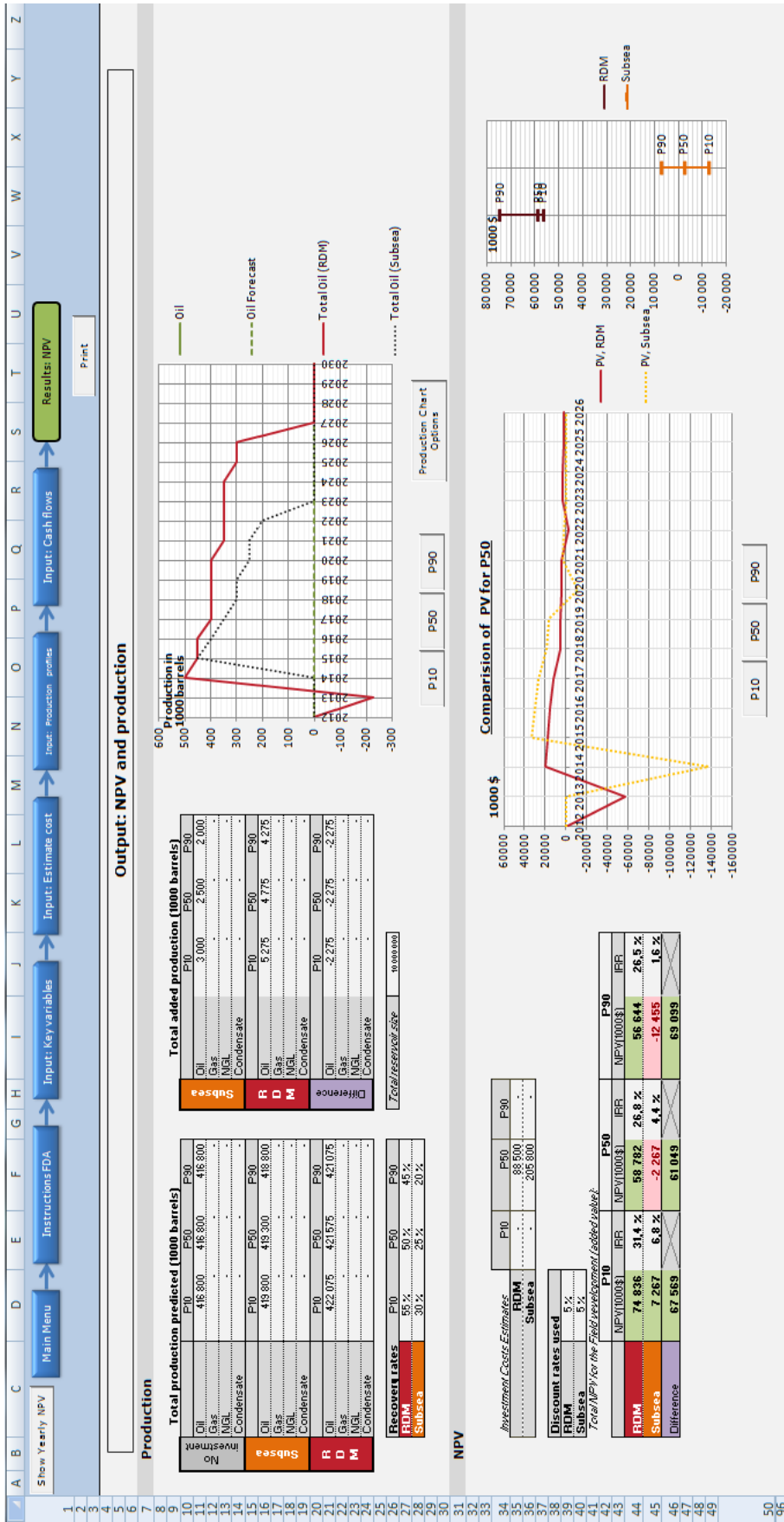


Figure D3.6a – Results: NPV.

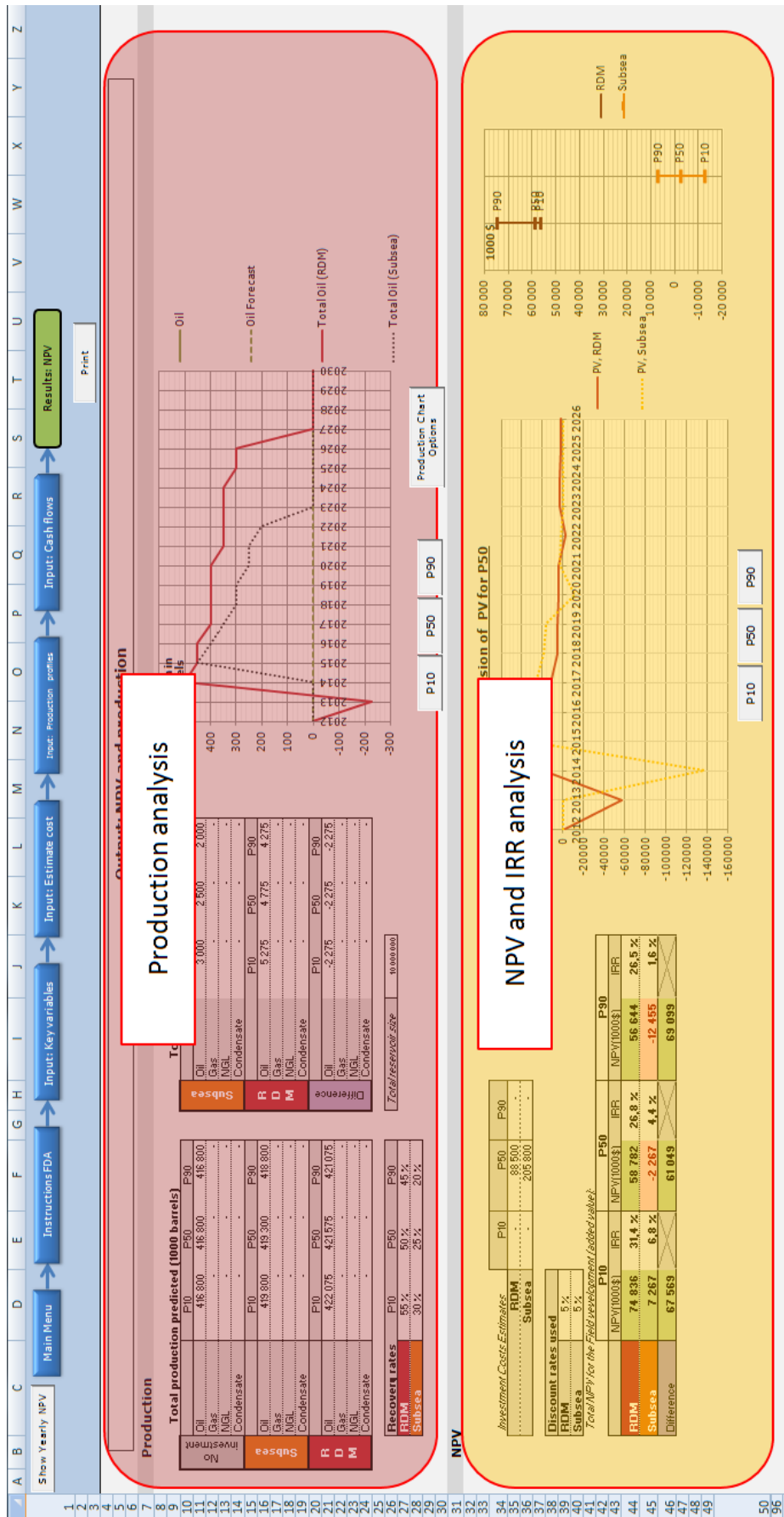


Figure D3.6b – Results: NPV.

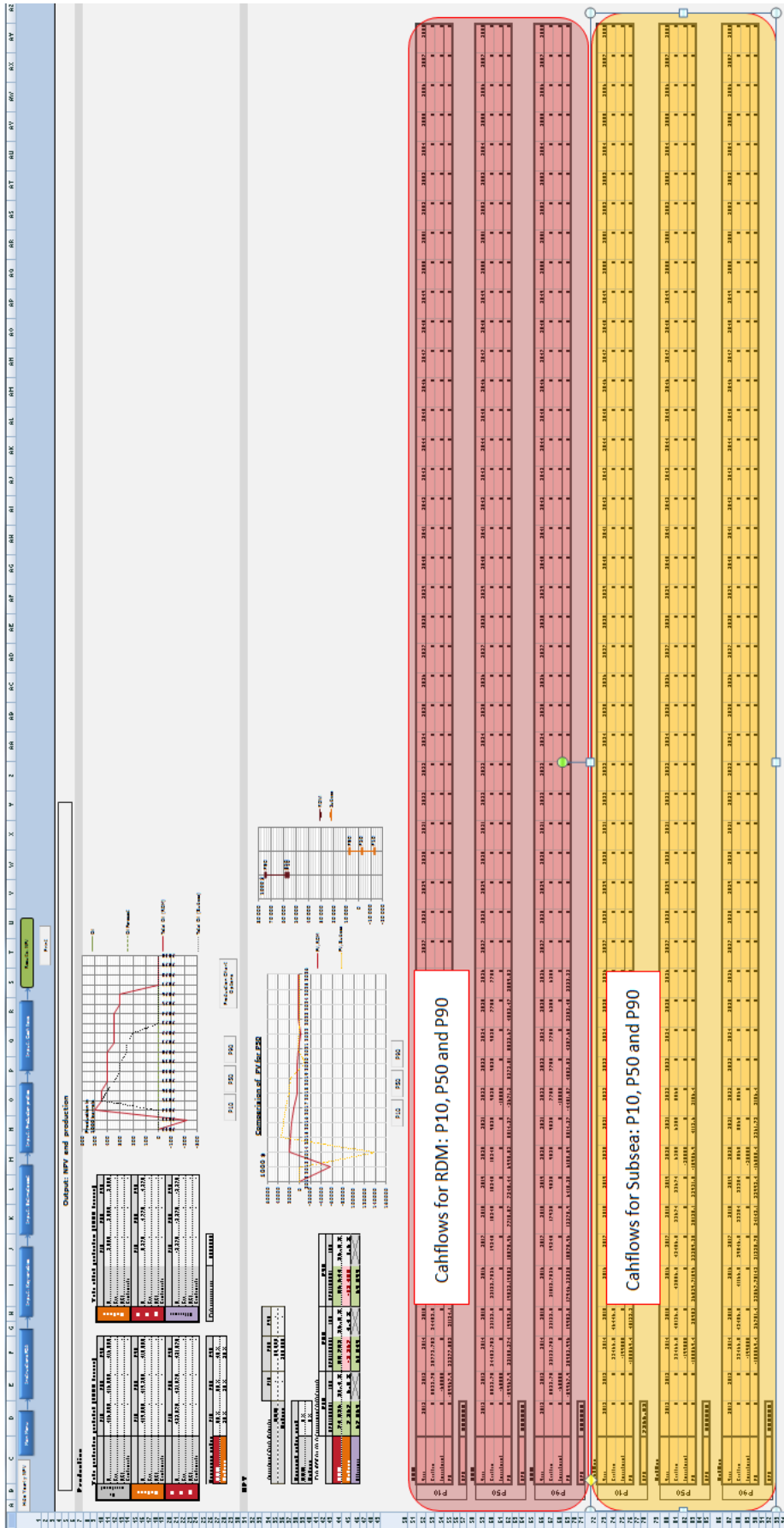


Figure D3.6c – Results: NPV expanded to view yearly cash flows for RDM and SubSea.

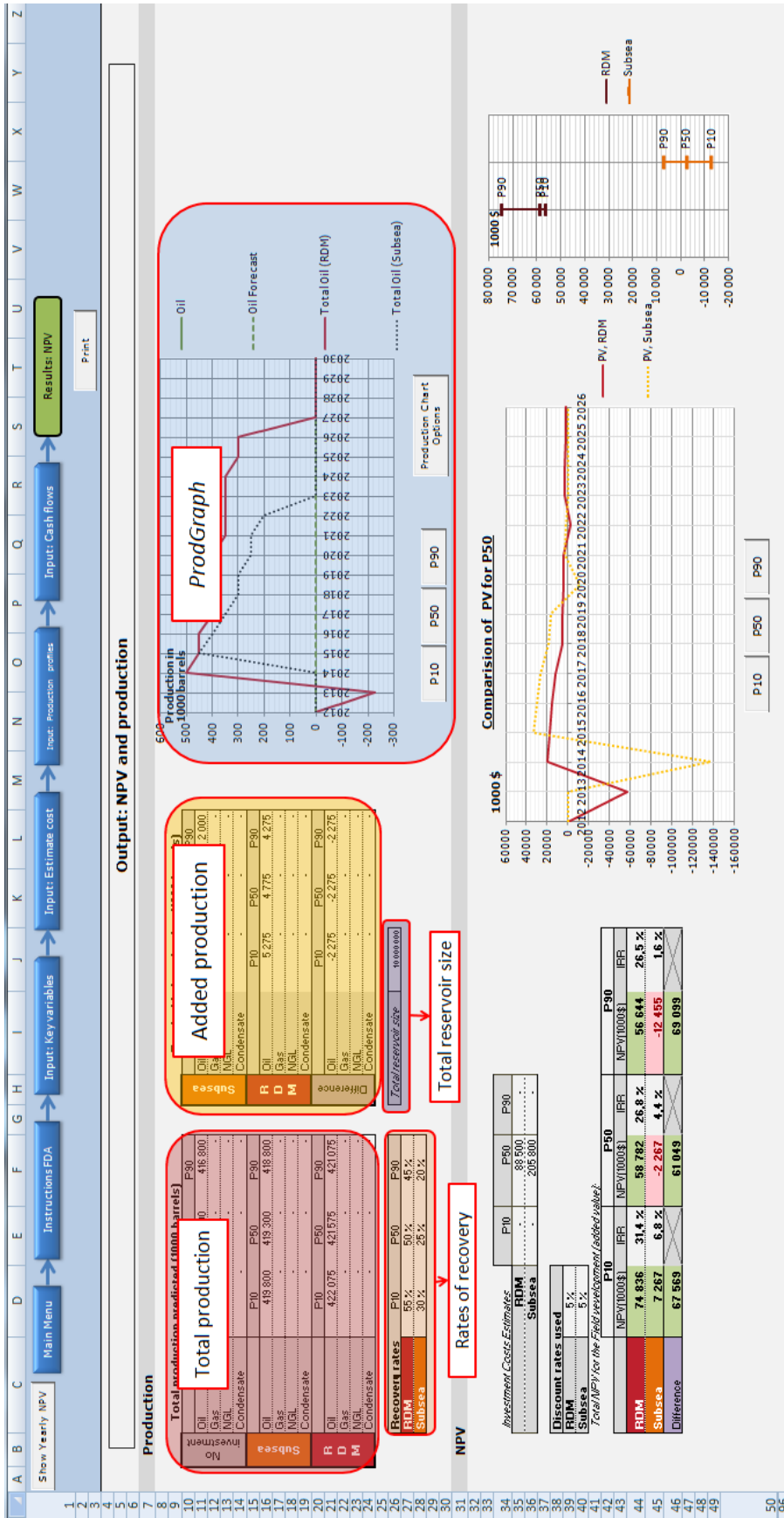


Figure D3.6d – The production section of Results: NPV explained.

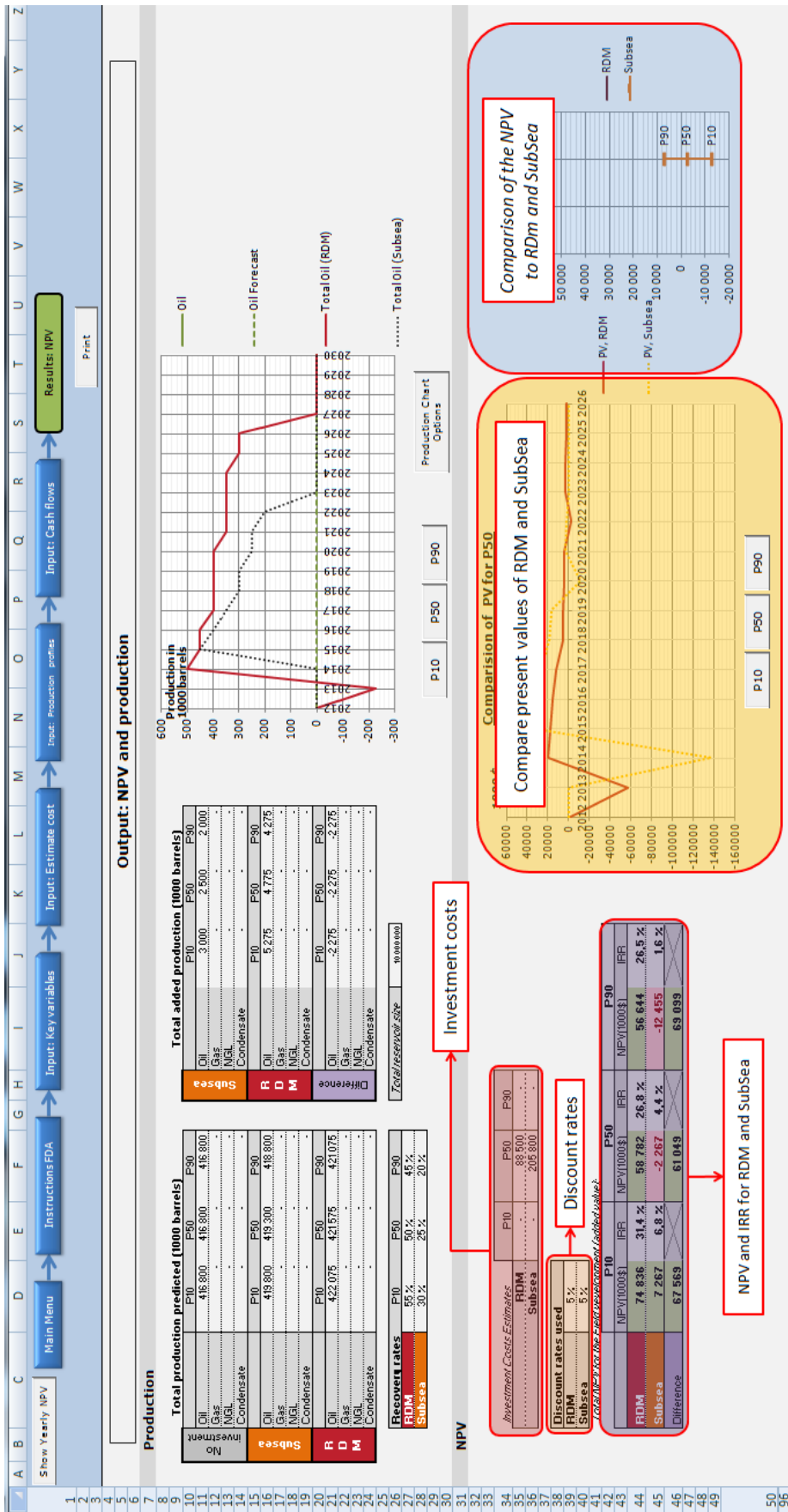


Figure D3.6e - The NPV section of *Results: NPV* explained.