Deliverable D2.4

Report on well assessment tool demonstration results and updates

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Executive summary

After initial development and release of the *beta* version of the REX-CO_2 well screening tool, a feedback cycle was incorporated to provide advice and suggestions for a version 1.0 of the tool. The feedback has been collected through a series of discussions between members of WP2, which deals with the workflow and tool development; a workshop with project partners on format and structure of decision trees used in the tool; and a workshop with members of WP4, which performed a test application of the *beta* version of tool using national case studies and helped to identify bugs as well as new features to improve tool usability. The feedback received through the discussions and workshops resulted in a list of suggested updates which were prioritized and implemented in the *beta* version and led to development of the v1.0 release version. The updates address issues related to workflow, the decision trees, and functional aspects of the tool's user interface.

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1. Introduction

One of the primary outputs of the REX-CO_2 project is an assessment tool to help screen existing wells for re-use in CO_2 storage. The foundation behind this tool is a workflow which guides a user through several questions about various aspects of the well they are interested in re-using and was described in deliverable "D2.2: Summary report of well assessment tool framework" (Pawar et al, 2020a). The workflow was developed based on a literature review (deliverable "D2.1 Current state-of-the-art assessments and technical approach for assessment of well re-use potential and CO_2/brine leakage risk" (Opedal et al., 2020) as well as the expertise among the partners within the consortium. The workflow attempts to assess a well's suitability to maintain its integrity throughout the expected lifetime of the well. In order to implement the workflow within the project, multiple decision trees have been developed to assess the integrity of a well being considered for re-use as a CO_2 storage well. These decision trees have been incorporated into a *beta* version of the REX-CO_2 well screening tool. More details on the tool and initial decision trees can be found in deliverable "D2.3: Report on REX-CO_2 well screening tool" (Pawar et al., 2020b).

This deliverable, "D2.4: Report on well assessment tool demonstration results and updates", builds on the *beta* version of the tool and describes the process followed to receive feedback from the consortium and update the tool. The feedback has been primarily of interest for WP2, which deals with the development of the workflow and tool, and WP4 (application of the tool to national case studies) in order to provide comments and suggestions related to functionality and usability of the tool as well as an initial demonstration of the tool. This served as an important step to test the tool on multiple computer configurations and provided a robust picture of tool performance across various computational platforms. Following the current update, the tool will be applied by WP4 to perform an analysis of the national case studies.

This report describes the process undertaken to demonstrate the tool to the consortium members and receive their feedback (Section 2) and the issues encountered and the updates (for both the workflow as well as the graphical user interface, or GUI) implemented to develop the next version (v1.0) of the tool (Section 3).

2. Demonstration results

2.1. Feedback timeline

The workflow and the decision trees used to develop the screening tool were discussed in an internal REX-CO_2 workshop on 15 October 2020, in order for the partners to understand the framework underlying the queries asked during application of the tool. The workshop served as a session where the partners could provide feedback and suggestions on the decision trees.

The initial, or *beta*, version of the REX-CO_2 tool was developed and distributed among the consortium members in November 2020. Both the WP2 and WP4 team members performed preliminary test runs of the tool. The objective was to have an initial interaction with the tool and its functionality and provide feedback on the functionality and usability of the tool.

On 14 December 2020, a feedback session was held with the WP4 team to gather their overall impression and feedback on usability of the tool through application to real data from national case studies. Through this workshop we were able to identify the primary issues encountered when using the tool and subsequently update the tool to address the core issues.

During this period the decision trees have also been continually updated taking into consideration the suggestions from the consortium partners

2.2. Demonstration feedback

To facilitate the feedback cycle, a spreadsheet was developed to catalog and track the issues encountered while using the tool as well as other suggestions and comments. The spreadsheet was organized with following columns:

- Part of the tool – where in the tool the issue was found (e.g. General, Dashboard, Tool Initialization, Well Screening, or Cement Integrity Predictions).
- Type of issue – this could be a bug, suggestion, comment, or other.
- Description of issue – information about the issue.
- Importance – ranking of how important this issue is (high, medium, or low).
- Submitted by – main contact of who encountered this issue.
- Supported by – names of others who support this issue.
- Initial assignee – who should address this first: the general WP2 partners or with the WP2 tool developers.
- Comments – additional information about the issue.

In preparation for the WP4 feedback session, the partners were asked to structure their feedback along the following points: general impressions, what works nicely, must-have updates, and nice-to-have updates. These were identified and further discussed during the online workshop. The following sections cover the specific items that were requested in both the WP2 and WP4 feedback sessions on the tool.

2.3. Feedback

The following sections provide a summarized collection of the issues that were raised by WP2 and WP4 team members, starting with the general impressions and followed by textual or clarifying suggestions, suggestions to the inputs, and functional suggestions. We were not able to address all the issues during v1.0 update of the tool. Section 3 provides details of the specific issues that were addressed.

2.3.1.1. General impressions

- Using the tool is a smooth experience
- Easy to understand and intuitive to use
- Clearly organized and navigates well
- Main features work as expected
- Looks like a complete technical tool
- Need to adjust certain functionalities of the tool

2.3.1.2. Textual/clarification suggestions

- Update of the text in the decision trees. Fix some inconsistencies with some questions.
- Clarification of the data availability checkboxes to be yes or no options instead. Provide detailed explanations of the recommended data for assessment with the checkboxes.
- Not clear where the data requested from the data availability checkboxes is used.
- Provide more inputs about fault reactivation.
- Certain characters are not allowed in the input fields.
- Provide more specific recommendations about what the deciding component is when completing the well screening decision trees.
- Clarify abbreviations and acronyms throughout the tool.
- Rephrase lengthy questions in the primary and secondary barrier decision trees of the well screening.
- Inform user that the decimal separator used in this tool is a period and not a comma.
- Add more detailed explanation of the cement integrity predictions and what is being modeled there.
- Explain what certain specifications mean, for example the Dynamis specification which is asked about the injected CO_2.

2.3.1.3. Suggestions to the inputs

- Prefer to have capability of using different units (e.g. SI, US customary, etc.) for the inputs.
- In the cement integrity predictions, define the well type based on generic features of that well and have the tool suggest an appropriate well type
- Allow more options for the types of reservoirs.
- Allow more than 9 wells to input.
- Reduce the number of inputs that aren't used in the tool.
- Change the well input from well with a well name to well type to define multiple similar wells.
- Add an option to select "abandoned" to the intended use of a well.
- Explain what the model options selection means in the cement integrity predictions. Possibly add several inputs that the user could select, and then the model suggests the closest option.

2.3.1.4. Functional suggestions

- Add the functionality to save and load previously entered data.
- On computers with another system language, clicking the popup options doesn't work.
- Tool can take a while to open on some computers.
- Resizing of the window has little effect
- Some of the inputs are pushed off screen
- Enable filling out the decision trees for all questions, even if some information is missing.

- Allow the viewing of the decision tree results even if not all the decision trees are complete.
- Enable use of tool on computers with different languages.
- Add a button to access the user manual from every page in the tool.
- The scroll wheel on the mouse doesn't work for the scrollbars in the tool.
- Add a progress bar below the decision trees to know how far the user is through the decision trees.
- Add image of a well (e.g. from API or NORSOK) and its components next to the decision trees to show what these are.
- Add a next button on the tool initialization pages and decision trees to be able to go to the next input or decision tree.
- When the cement integrity predictions are running, notify the user somehow that the model is running.
- No clear exit button in the tool except the close "X" in the top corner.
- Allow the user to download a PDF of the decision trees, to see the logic behind the workflow themselves.

3. Tool updates

3.1. Workflow/decision tree updates

The following points are the updates for the foundational workflow, which more specifically was a change in the decision trees that were made.

- Label each question in the decision trees with an ID which will be subsequently used as part of the results summary to provide specific details.
- Previously, when the user reached a certain point in the tree with enough negative responses, the tree would skip the remaining questions and display the recommendation for the well. The trees have been updated so that the user can continue answering all questions despite having answered negatively to previous questions.
- One major update implemented in the decision trees is providing a user the capability to answer a query with a “Don’t know” option (in addition to the “Yes” or “No” options) following feedback received during October 2020 feedback workshop. In order to respond to different queries in a decision tree, a user is expected to have access to relevant information or data for the well such as its design, completion, status of well components, results of tests performed for verifying its integrity, etc. In the case that the relevant information is not available the user is provided the option of “don’t know” or “missing data” response. The responses to all queries for each of the assessments (well integrity, risk of out of zone injection, material compatibility, and structural integrity) are recorded and are collectively used to determine if:
    - The well in its current state meets the requirements for each of the assessments and can be used for CO_2 storage application without any modification.
    - The well in its current state may not meet the requirements for each of the assessments but can be used for CO_2 storage application with some modifications.
    - The well in its current state may not meet the requirements for each of the assessments and its use for CO_2 storage application will require significant modifications.
- At the end of the assessment a user is provided with results indicating one of the above. We require that in order for a well to be re-used in its current state (without any remediation or workover) it has to meet all the requirements for each of the four well design-related assessments. If a well fails one or more of the four, the result indicates that the well can either be used for a CO_2 storage application with some modifications in order to satisfy all the requirements or would require significant modifications in order to make it usable. The tool is updated to provide a user with a list of the issues that need to be addressed to meet the requirements. In addition, the user is recommended to perform a detailed techno-economic evaluation as part of the overall feasibility evaluation. In the case that a user does not have relevant data or information and responds with the “don’t know” or “missing data” option, the user is provided with a recommendation that critical information needed for assessment is missing along with a list of information that the user should collect to provide with a proper evaluation. In certain cases, missing data may result in a decision of not re-using the well rather than collecting additional information. Appendix A gives an example of the updated version of the decision tree for assessing integrity of primary barrier as part of the well integrity assessment. All the updated decision trees are available on the REX-CO_2 share point site.

3.2. Graphical user interface updates

The development of the Python-based graphical user interface (GUI) was undertaken by a small team within WP2. The library used for the GUI is *Tkinter*, which is both free and cross-platform. The tool was bundled using the *PyInstaller* Python library, which can package the tool for both Windows and Mac operating systems. The code is hosted on TNO's GitLab, which has also served as the main issue tracker for the development of this software.

3.2.1. v0.1 (*beta*) features

The main goal of the *beta* version was to provide a base tool that would serve as a starting point to provide updates and improvements. The following describes the main functionality included in this *beta* version (v0.1), arranged by the various pages (which are written in **bold** throughout this section):

- **Disclaimer** page
  - Displays the project disclaimer for using the tool.
  - Passes the user on to the **Dashboard** page.
- **Dashboard** page
  - Link to the **Tool Initialization** page.
  - Link to the **Well Screening** page, which is only enabled when at least one well has been input by the user in the **Tool Initialization** page.
  - Link to the **Cement Integrity Predictions** page.
  - Link to open the user manual with the system's default PDF viewer.
  - Popup with acknowledgements.
  - Popup with references.
- **Tool Initialization** page
  - 4 tabs containing various inputs on the following:
    - General – higher-level information on the field and location.
    - Data Availability – checkboxes to suggest what data is recommended for this assessment.
    - Reservoir – information about the reservoir and caprocks, as well as selection of additional caprocks.
    - Well Data – selection of how many wells the user is assessing and basic information on these wells. This well selection is linked to the wells that are displayed on the **Well Screening** page.
  - Link to return to the **Dashboard** page.
- **Well Screening** page
  - Shows the number of wells the user will assess, which contains a green checkmark if all of that well's decision trees have been completed.
  - Link to each well's **Decision Tree** page.
  - Link to **Well Screening Results** page, which is only enabled when all the decision trees for all the wells have been filled out.
  - Link to return to the **Dashboard** page.
- **Decision Tree** page
  - 5 tabs containing the different decision tree questions:
    - Out of zone injection
    - Structural integrity
    - Well integrity primary barrier
    - Well integrity secondary barrier
    - Material compatibility
  - Recommendation listed below each decision tree once that decision tree has been filled in.
  - Link to return to the **Well Screening** page.

- **Well Screening Results** page
  - Shows the overall recommendation of each well, arranged by severe, moderate, or minor remediation required.
  - Shows a color table of the recommendation of each decision tree for each well.
  - Shows the breakdown of each decision tree recommendation for each well.
  - Link to return to **Well Screening** page.
- **Cement Integrity Predictions** page
  - Link to return to the **Dashboard** page.

3.2.2. v0.2 (*beta*) hotfix

After the initial release, it was discovered that the confirmation popups within the tool were incompatible with different languages (i.e. the tool showed the user the popup responses in their system's native language, so when the user clicked on one of the options, the system sent the foreign language response to the tool, which was not one of the accepted responses of "Yes", "No", or "Cancel"). Due to this bug, we implemented one hotfix to release to the consortium on short notice, which is noted as *beta* version v0.2.

3.2.3. v1.0 updates

After receiving the feedback from the WP2 and WP4 partners (see Section 0), an abbreviated selection of possible updates was decided upon, given the remaining time and budget. The following list contains these updates for v1.0 of the tool:

- Bug fixes
  - Provided more detailed explanations on the various pages of the tool.
  - Enabled all characters to be input in the text fields on the **Tool Initialization** page under the "General" tab, which previously had restricted certain characters.
  - Fixed the use of slashes in the default save path on the **Tool Initialization** page.
  - The tool was not appearing correctly on all screen resolutions (i.e. the tool window extended beyond the edge of the user's computer, and so the buttons were not seen and also could not be clicked), so it has been made into a small enough window to appear correctly at most resolutions.
  - Shifted the "Well Data" tab on the **Tool Initialization** page to the second tab position, since that is the main tab needed to complete the well screening.
  - Added scrollbars **Tool Initialization** tabs and the **Decision Tree** pages which previously extended the tool window.
  - Prevented deleting the previously input well data when the user changes the number of wells on the **Tool Initialization** page.
  - Fixed the button to the user guide on the **Dashboard** page which was not working.
  - Fixed the selection options in the **Tool Initialization** page from being pushed outside of the GUI window.
  - Fixed general typos and missing units.
- Features added
  - Added ability to save the inputs found on the **Tool Initialization** page and load these inputs back into the tool.
  - Added ability to save the inputs and results from the **Decision Tree** pages and the **Well Screening Results** page and load these values back into the tool.
  - Enabled selecting and inputting more than 9 wells into the **Tool Initialization** page.
  - Allowed user to select "No re-use" as an "Intended Use" for wells on the **Tool Initialization** page, which do not show up on the **Well Screening** page but do

show up on the **Well Screening Results** page as a well that will not be re-used.

- Updated the **Decision Tree** pages to their most recent versions. This includes the following:
  - Incorporated the “unknown” option to the decision trees.
  - Enabled the continuation of the decision trees through each question regardless of the user’s answers.
  - Added a color response for each question within the decision trees to let the user to see how that question ranks.
  - Added a color recommendation at the bottom of each decision tree.
  - Added a button to open the specific decision tree in the system’s default PDF viewer.
- Enabled the user to view the **Well Screening Results** page as long as at least one well’s set of decision trees is complete.
- Enabled threading when running the simulation on the **Cement Integrity Predictions** page, to prevent the tool from appearing frozen. Grayed out the button when the simulation is running and then re-enabled it when the simulation has concluded.
- Added link to open the user manual from each page in the tool.

4. Conclusion

This deliverable, “D2.4: Report on well assessment tool demonstration results and updates”, describes the steps in going from the *beta* version of the REX-CO_2 well screening tool to an updated version (v1.0). The decision tree workflows and the *beta* version of the tool were distributed among the consortium to review. A series of workshops were then organized to show and explain these workflows and the tool as well as collect the user feedback. From the comprehensive list of suggestions and comments, the WP2 team narrowed this down to a short list of main issues to address in the update of the tool. These updates include functional and textual features within the tool, as well as a robust update of the foundational decision tree workflows. Going forward, this updated version of tool will be used to perform the well screenings on the various national case studies as defined in WP4.

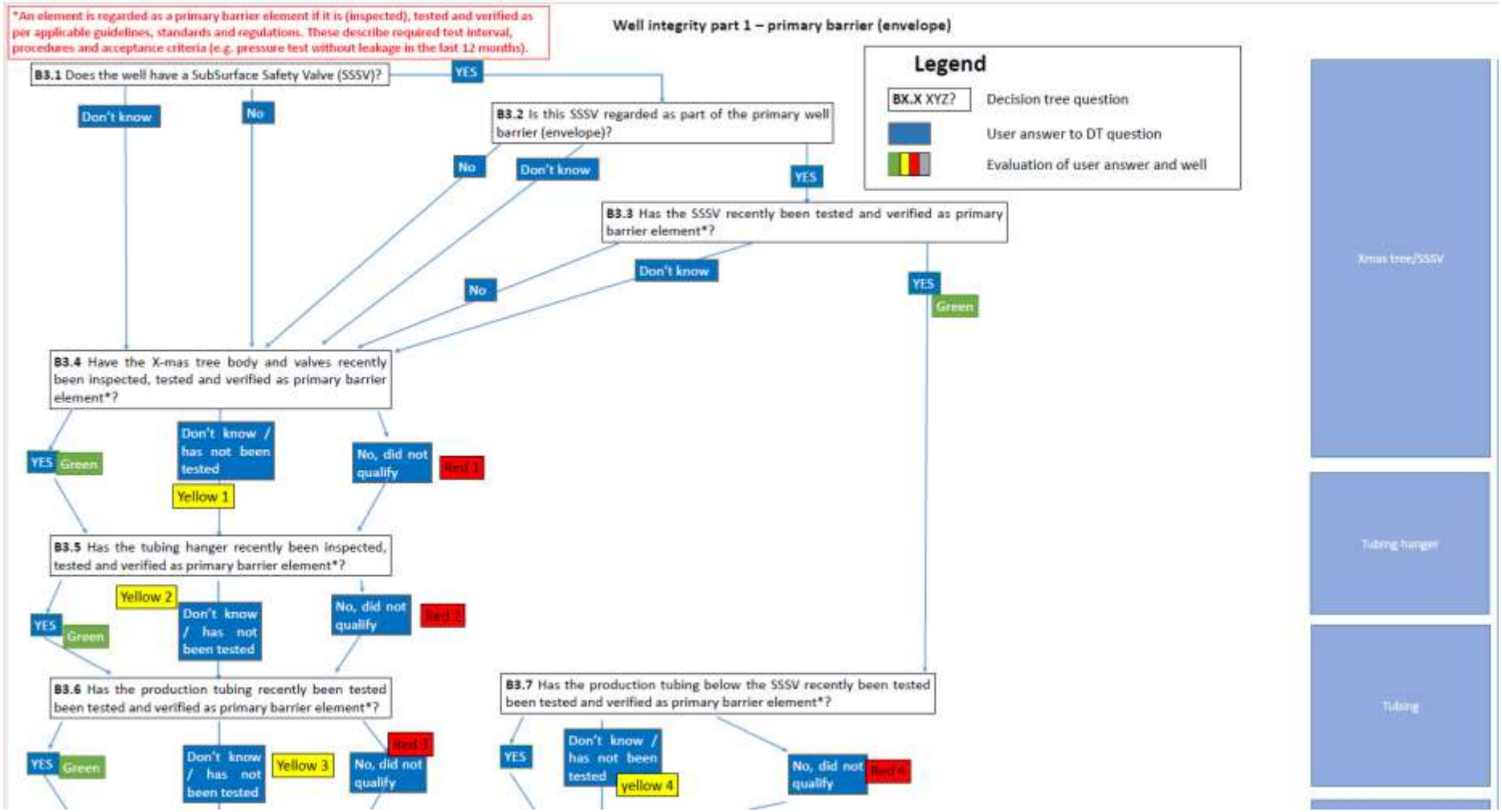
5. References

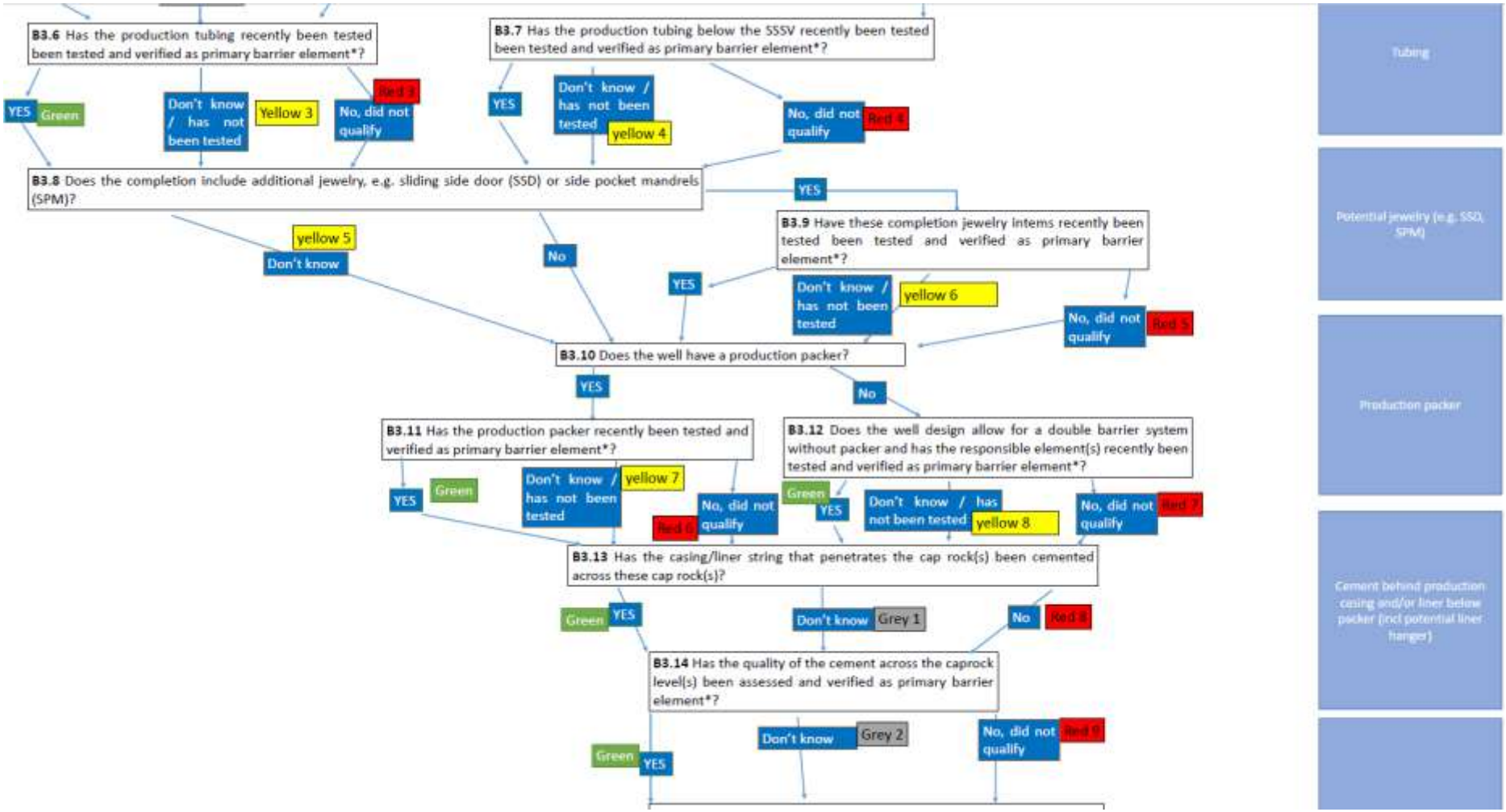
Opedal, N., van der Valk, K., Williams, J., Greenhalgh, E., Brunner, L., and Pawar, R., 2020. REX-CO_2 Deliverable D2.1-Current state-of-the-art assessments and technical approach for assessment of well re-use potential and CO_2/brine leakage risk

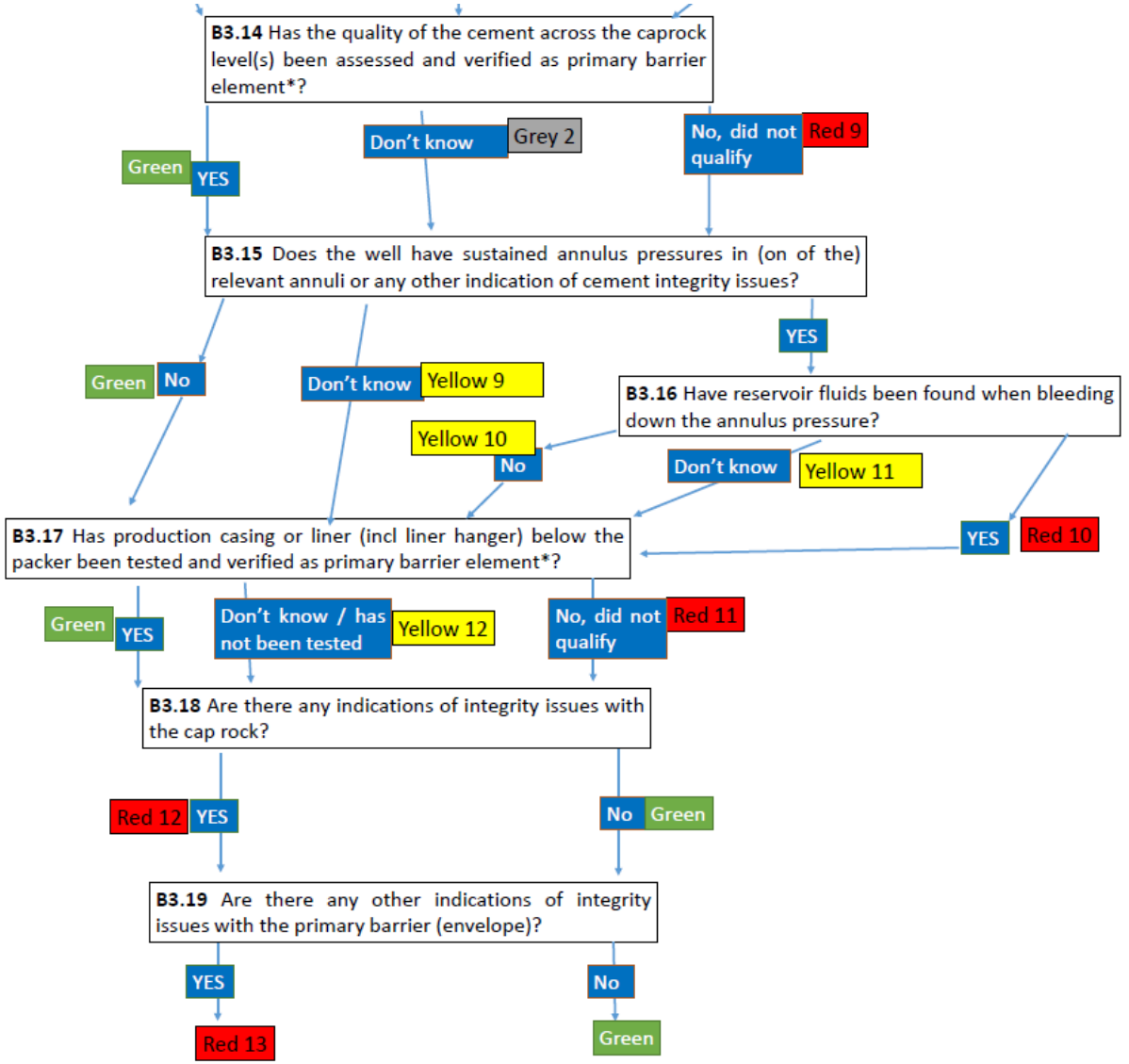
Pawar, R.J., van der Valk, K., Brunner, L., Cangemi, L., Chen, B., Dudu, A.C., Greenhalgh, E., Harp, D., Opedal, N., and Williams, J., 2020a. REX-CO_2 Deliverable D2.2 – Summary report of well assessment tool framework.

Pawar, R.J., van der Valk, K., Brunner, L., van Bijsterveldt, L., Chen, B., Harp, D., Cangemi, L., Dudu, A.C., Guy, N., Opedal, N., and Williams, J., 2020b. REX-CO_2 Deliverable D2.3 – Report on the REX-CO_2 well screening tool.

Appendix A. Updated decision tree for assessing well integrity




B3.6 Has the production tubing recently been tested been tested and verified as primary barrier element*?
YES
Green
Don't know / has not been tested
Yellow 3
No, did not qualify
Red 3
B3.7 Has the production tubing below the SSSV recently been tested been tested and verified as primary barrier element*?
YES
Don't know / has not been tested
yellow 4
No, did not qualify
Red 4
B3.8 Does the completion include additional jewelry, e.g. sliding side door (SSD) or side pocket mandrels (SPM)?
YES
yellow 5
Don't know
No
B3.9 Have these completion jewelry items recently been tested been tested and verified as primary barrier element*?
YES
Don't know / has not been tested
yellow 6
No, did not qualify
Red 5
B3.10 Does the well have a production packer?
YES
No
B3.11 Has the production packer recently been tested and verified as primary barrier element*?
YES
Green
Don't know / has not been tested
yellow 7
No, did not qualify
Red 6
B3.12 Does the well design allow for a double barrier system without packer and has the responsible element(s) recently been tested and verified as primary barrier element*?
Green
YES
Don't know / has not been tested
yellow 8
No, did not qualify
Red 7
B3.13 Has the casing/liner string that penetrates the cap rock(s) been cemented across these cap rock(s)?
Green
YES
Don't know
Grey 1
No
Red 8
B3.14 Has the quality of the cement across the caprock level(s) been assessed and verified as primary barrier element*?
Green
YES
Don't know
Grey 2
No, did not qualify
Red 9
Tubing
Potential jewelry (e.g. SSD, SPM)
Production packer
Cement behind production casing and/or liner below packer (incl potential liner hanger)


B3.14 Has the quality of the cement across the caprock level(s) been assessed and verified as primary barrier element*?
Green
YES
Don't know
Grey 2
No, did not qualify
Red 9
B3.15 Does the well have sustained annulus pressures in (on of the) relevant annuli or any other indication of cement integrity issues?
Green
No
Don't know
Yellow 9
YES
B3.16 Have reservoir fluids been found when bleeding down the annulus pressure?
Yellow 10
No
Don't know
Yellow 11
YES
Red 10
B3.17 Has production casing or liner (incl liner hanger) below the packer been tested and verified as primary barrier element*?
Green
YES
Don't know / has not been tested
Yellow 12
No, did not qualify
Red 11
B3.18 Are there any indications of integrity issues with the cap rock?
Red 12
YES
No
Green
B3.19 Are there any other indications of integrity issues with the primary barrier (envelope)?
YES
Red 13
No
Green
Additional indications of cement quality
Production casing and/or liner hanger
Caprock
Any other indications

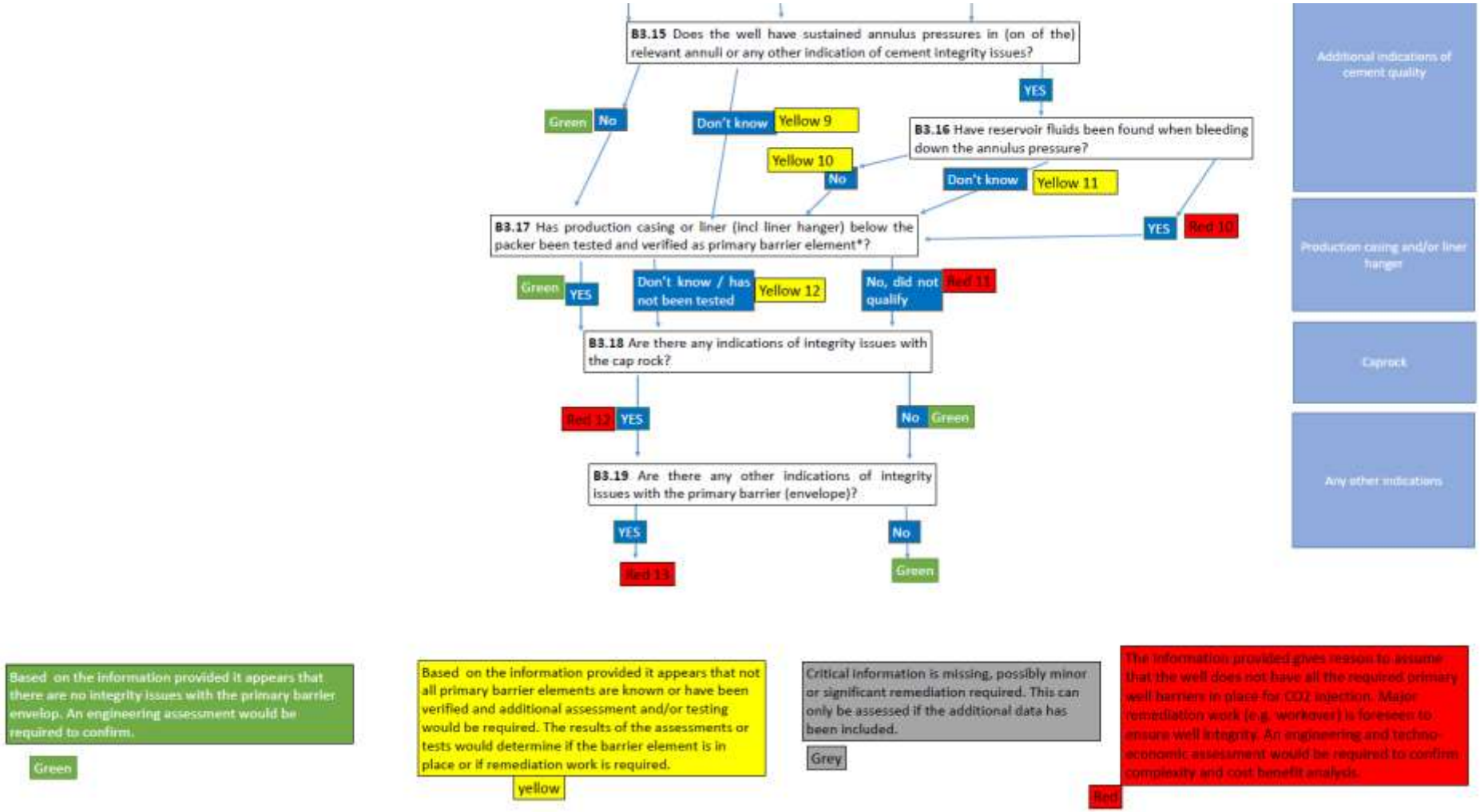


Figure 1. Updated decision tree for assessing the well integrity of the primary barrier. This now includes the ability to move through the entire decision tree despite reaching a negative recommendation, as well as the option to answer "Don't know" to certain questions.