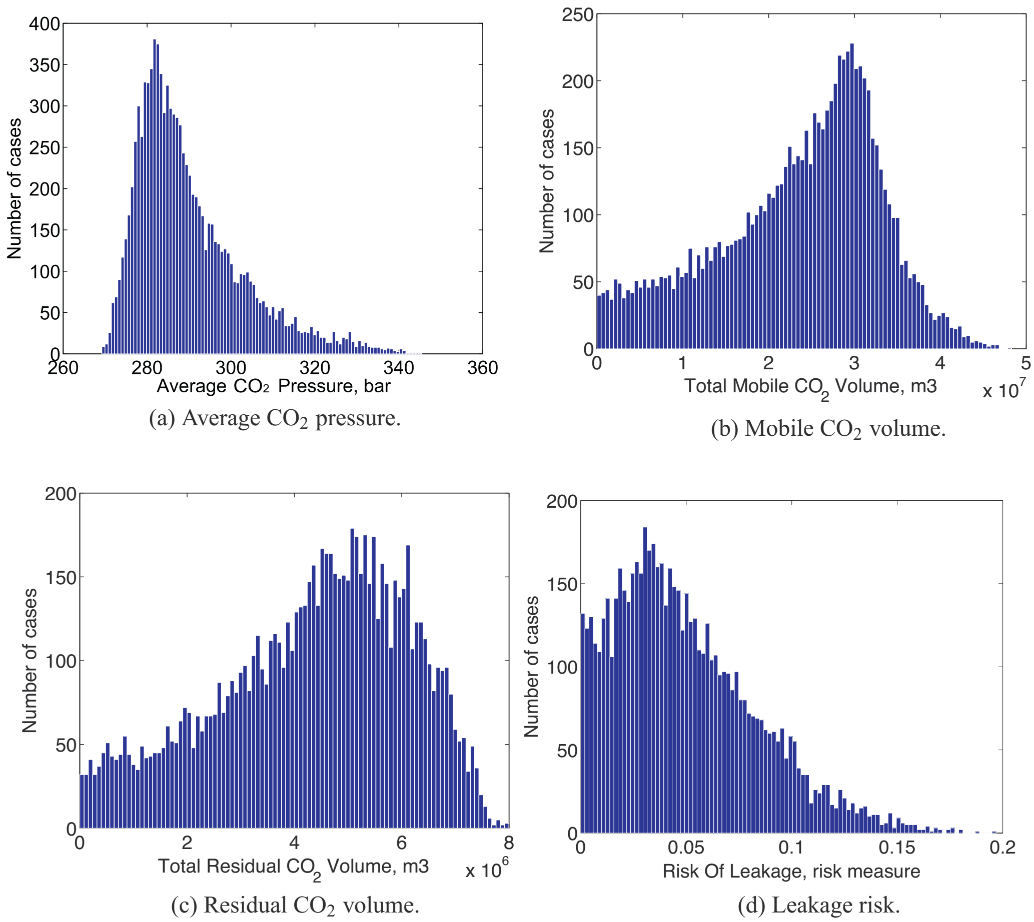

(a) Average CO_2 pressure.

(b) Mobile CO_2 volume.

(c) Residual CO_2 volume.

(d) Leakage risk.

Fig. 12. Histograms of selected response values at end of injection.

stabilize at a stationary condition for the majority of the model runs.

As already observed in Ashraf et al. (2010a,b), the aggradation angle plays a significant role in the flow behavior. In cases with low aggradation angle, the stratigraphy of rock types is a pattern of parallel layering. For higher aggradation angles, rock-types are distributed between more modeling layers. The effective vertical permeability changes from the harmonic average (in Fig. 9a) toward the arithmetic average (in Fig. 9c), as the aggradation angle increases from 0 to 90°. The harmonic average might be much smaller than the arithmetic average, in particular when there are vertically impermeable rock-types in the medium. The shallow marine depositional system contains some rock-types with almost zero transmissibility in the vertical direction. Therefore, a low aggradation angle can hinder the flow from traveling upward across layers in the domain and force it to stay trapped in some lower layers, as seen for many of the low aggradation angle realizations in our study. The relatively large sensitivities to the level of barrier presence are based on the same effects.

Our results show a relatively weak sensitivity of responses with respect to the water influx from one side of the model. This sensitivity is in particular low during injection, when the high pressure imposed from the well dominates the dynamics of flow in the medium (Fig. 8a). The sensitivity patterns for the mobile and residual CO_2 volume are similar in Fig. 8b and c, because the mobile and residual CO_2 volume add up to the total injected CO_2 volume, with the exception of the CO_2 volume that has left the domain. Hence, they are highly dependent on each other. More detailed results are shown in Fig. 10a–d. Total Sobol indices are plotted for each response during the entire time interval. When the flow regime switches from injection to a gravity-dominated system, we observe a jump or sharp drop in some of the sensitivity plots (Fig. 10a and c at 30 years).

The sensitivity of the CO_2 pressure with respect to the presence of barriers jumps up, right after stopping the injection. This happens because barriers slow down the pressure release through open boundaries, resulting in local pressure build-ups.

The sensitivity of the residual CO_2 volume with respect to barriers presence drops soon after injection. This is reasonable since the residual trapped volume is more a function of lateral flow in the medium, compared to the vertical flow in the relatively small thickness of the aquifer.

5. Risk analysis

The risk R of a process is quantitatively defined as the extent of consequence C caused by the process, multiplied by the probability P of that consequence to happen:

$$R = P \times C. \tag{12}$$

The consequence can be defined by direct measures in the simulation responses, or it can be related to consequences caused in the environment outside the considered system. For example, in the case of CO_2 injection into deep aquifers, the amount of CO_2 which stays mobile and undissolved in the medium for a time after injection can be considered as a consequence, bearing the potential of leakage up to the surface if exposed to a geological leakage point. The consequence could also be defined by a criterion for external consequences, like the rate of climate change (either locally or globally) due to CO_2 leakage, the costs of pumping CO_2 that does not