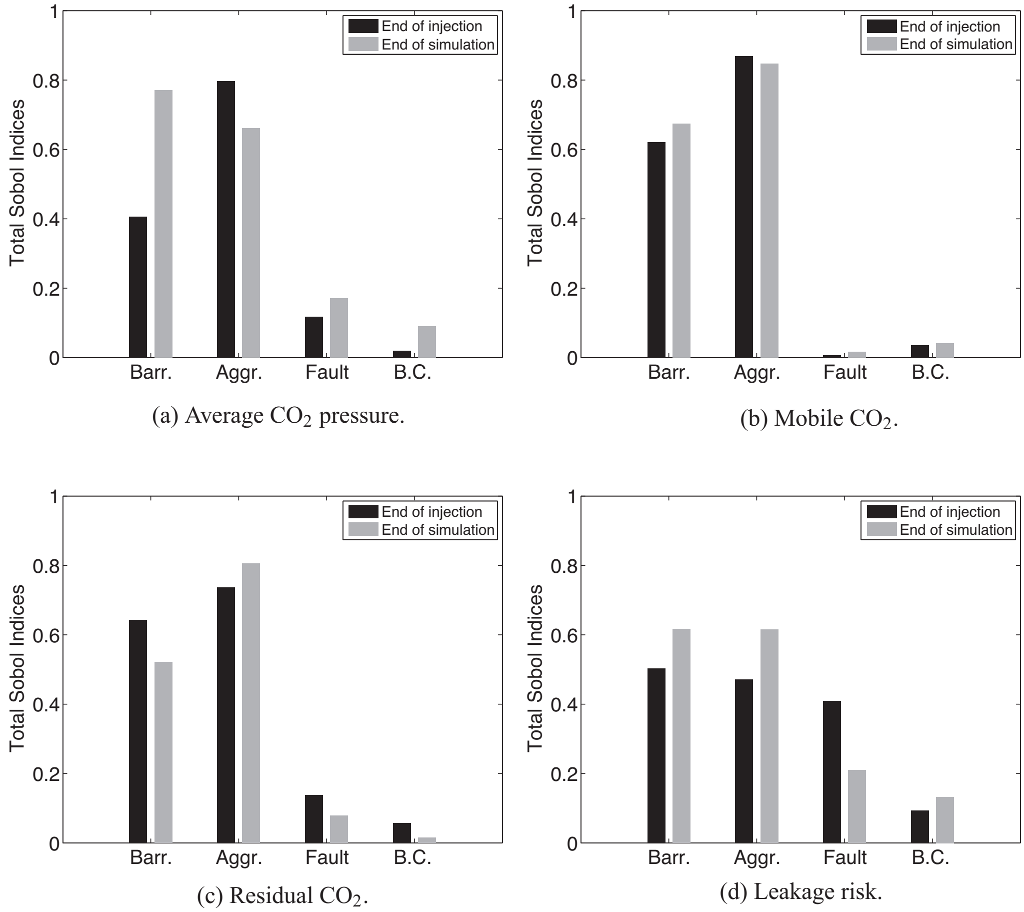

Fig. 8. Sensitivity analysis for different responses (a)–(d) with respect to the uncertain parameters. In the figures above, Barr. is for barriers, Aggr. for aggradation angle, Fault for fault transmissibility, and B.C. for regional groundwater effect.

4. Sensitivity analysis

In this section, we tackle global sensitivity analysis with Sobol indices based on the aPC technique, following the line of work on aPC by Oladyshkin and Nowak (2012) and Oladyshkin et al. (2011, 2012). The big advantage of global aPC-based sensitivity analysis is that one can obtain global sensitivity information at computational costs that are hardly larger than those for local analysis. The reason is the following: local methods use infinitesimally small spacing between parameter sets for model evaluation to get numerical derivatives evaluated at a single point. The aPC-based method places the parameter sets for model evaluation at an optimized spacing in parameter space. This can be interpreted as fitting secants (or polynomials for non-linear analysis) to the model response. These secants (polynomials) approximate the model over the entire parameter space in a weighted least-square sense (compare with the best unbiased ensemble linearization approach described by Nowak (2009)). This is more beneficial compared to computing a tangent or local second derivatives (compare FORM, SORM methods, e.g., Jang et al., 1994) that approximate the model well just around one point in the parameter space.

The system featured here is non-linear due to two reasons: First, the involved multi-phase flow equations Oladyshkin et al., 2011 form a coupled system of non-linear partial differential equations, and second, these equations are non-linear in their coefficients. The latter is even more significant if parameters are spatially heterogeneous.

In the following, we briefly summarize the Sobol sensitivity indices technique for quantifying the relative importance of each individual input parameter in the final prediction. Then, we implement the method for our geological CO_2 storage problem, based on the aPC response surface.

The model responses featured here for global sensitivity analysis (this section) and for the probabilistic risk analysis (see Section 5) are listed in Table 2 and have been discussed in Section 3.1. In the sense of global sensitivity analysis Saltelli (2008), not only should the analysis technique be global, but also should the analyzed quantities be global. In the latter, global refers to the fact that they are relevant for the engineer, are crucial in decision processes, etc. For example, an overall leakage risk is more informative in final decisions than the leakage rate at a specific point, and a total stored volume of CO_2 is more informative for volumetric efficiency considerations of the reservoir than the CO_2 saturation at individual points.

4.1. Sobol sensitivity indices

The method is well described in the literature (Sobol, 2001; Saltelli, 2008, 2010; Reuter and Liebscher, 2008). More recent works are concerned about expediting calculation pace by computing Sobol indices analytically from polynomial chaos expansions (Crestaux et al., 2009; Oladyshkin et al., 2011, 2012; Le Maî tre and Knio, 2010; Sudret, 2008). The idea behind the combination of PCE techniques with Sobol indices is to replace the analyzed system with an approximating function which leads to mathematical and numerical benefits in the sensitivity analysis.