Electronic Supplementary Information for the manuscript

“Design of mesoporous $\text{SO}_4^{2-}/\text{ZrO}_2–\text{SiO}_2$$(\text{Et})$ hybrid material as an efficient and reusable heterogeneous acid catalyst for biodiesel production”

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Catalyst characterization

$^{13}$C CP-MAS NMR and $^{29}$Si MAS (b) NMR spectra were obtained on a Bruker NMR spectrometer. Chemical shift for both $^{29}$Si and $^{13}$C NMR were referenced to the peak for trimethylsilane at 0 ppm. Fourier transform infrared (FT-IR) spectrum on the powder sample mixed with KBr was recorded on a Nicolet Magna 560 FT-IR spectrometer at a resolution of 4 cm$^{-1}$. The concentration of the sample in KBr was kept around 0.25-0.3%. X-ray photoelectron spectra (XPS) were performed on a VG-ADES 400 instrument with Mg Kα-ADES source at a residual gas pressure of below 10$^{-8}$ Pa. All the binding energies were referenced to the C 1s peak at 284.6 eV of the surface adventitious carbon. Nitrogen porosimetry was performed on a Micromeritics ASAP 2020M instrument. The surface areas were calculated using the BET equation. Pore size distributions were calculated using the BJH model based on nitrogen desorption isotherms. The samples were outgassed under vacuum at 90 °C for 1 h and then 200 °C for 12 h.
Fig. S1 $^{13}$C CP-MAS NMR (a) and $^{29}$Si MAS (b) NMR spectra of the SO$_4^{2-}$/ZrO$_2$–SiO$_2$(Et)
material.
Fig. S2 FT-IR spectra of the $\text{SO}_4^{2-}/\text{ZrO}_2$–$\text{SiO}_2$(Et) material.
Fig. S3 XPS survey spectra for as-prepared $\text{SO}_4^{2-}/\text{ZrO}_2$–$\text{SiO}_2$(Et) and $\text{SO}_4^{2-}/\text{ZrO}_2$ materials in the Zr3d and S2p binding energy regions.

Fig. S4 Nitrogen adsorption-desorption isotherms (a) and pore size distribution (b)
profiles of ZrO$_2$–SiO$_2$(Et), SO$_4^{2\text{-}}$/ZrO$_2$–SiO$_2$(Et), SO$_4^{2\text{-}}$/ZrO$_2$–SiO$_2$, and SO$_4^{2\text{-}}$/ZrO$_2$ (insert) catalyst.