

TABLE 6. Performance Comparison (Precision, Recall and AUC) of Imbalanced vs. Balanced Sampling Methods. The base performance for each model is reported on imbalanced data (IB), with the values in square brackets indicating the difference when applying balanced-oversampling (BDO), balanced-undersampling (BDU), and balanced-hybridsampling (BDH).

Method	Precision IB [BDO, BDU, BDH]	Recall IB [BDO, BDU, BDH]	AUC IB [BDO, BDU, BDH]
Without hyper-parameter Tuning (WHT)			
Autoencoder	0.58 [+0.17, -0.38, -0.35]	54.29 [-32.33, -36.41, -36.12]	74.73 [-15.63, -18.06, -17.73]
Decision Trees	31.64 [-31.14, -31.14, -31.13]	3.66 [+91.48, +95.72, +90.48]	51.83 [+40.88, +42.79, +40.54]
Gaussian Naive Bayes	25.53 [-24.18, -25.08, -25.03]	27.12 [+3.30, +14.88, +8.38]	64.10 [-1.00, +0.10, -0.20]
Isolation Forest	12.22 [-10.02, -11.71, -11.72]	15.04 [+13.06, +25.06, +32.14]	58.55 [+6.45, +3.45, +0.75]
KNN	99.90 [-92.19, -99.40, -94.72]	99.98 [-67.78, -3.27, -65.47]	53.30 [+12.70, +39.28, +13.79]
LightGBM	31.02 [-30.24, -30.48, -30.27]	10.65 [+61.08, +87.93, +59.35]	55.32 [+28.16, +39.47, +33.38]
Random Forest	40.00 [-6.48, -7.78, -1.20]	25.44 [+19.56, +1.56, +6.56]	80.20 [+5.30, -0.10, +3.90]
Robust Covariance	4.10 [-3.70, -3.66, -3.58]	15.00 [+10.10, +21.11, +31.11]	59.12 [+1.08, +1.03, +1.21]
XGBoost	75.01 [-74.11, -74.48, -74.50]	39.91 [+42.49, +59.15, +57.59]	88.20 [-0.20, +6.71, +5.80]
ADMXGB	18.36 [+9.73, -1.20, +5.05]	99.96 [-13.55, -0.02, -5.39]	99.65 [-6.54, +0.11 , -2.50]
With hyper-parameter Tuning (HT) - Grid Search			
Autoencoder	0.64 [-0.38, -0.42, -0.36]	53.97 [-34.52, -35.48, -29.49]	74.79 [-17.25, -17.81, -14.77]
Decision Trees	42.32 [-41.49, -41.74, -42.31]	15.37 [+40.27, +78.70, +39.77]	57.68 [+18.44, +35.25, +18.59]
Gaussian Naive Bayes	35.45 [-33.44, -34.95, -34.93]	28.12 [+6.88, +14.98, +8.03]	65.88 [-0.38, -0.78, -0.38]
Isolation Forest	16.18 [-13.48, -15.62, -15.58]	17.22 [+13.11, +24.83, +31.78]	60.07 [+6.43, +2.93, +2.43]
KNN	40.87 [-28.82, -40.32, -35.33]	10.27 [+18.19, +83.07, +23.64]	55.13 [+9.05, +36.44, +11.67]
LightGBM	50.99 [-49.84, -50.43, -49.79]	20.00 [+65.13, +76.84, +55.00]	60.00 [+29.70, +34.13, +28.90]
Random Forest	45.18 [-10.78, -9.74, -5.98]	30.45 [+22.35, -2.33, +3.10]	82.95 [+5.80, -1.70, +2.55]
Robust Covariance	5.10 [-4.66, -4.62, -4.56]	22.50 [+6.20, +14.70, +25.50]	61.12 [-0.22, -0.02, -0.42]
XGBoost	80.15 [-78.95, +10.67, -79.60]	41.11 [+42.09, +58.89, +57.09]	90.00 [-0.90, +4.94, +4.60]
ADMXGB	47.50 [+52.31, +52.12, +52.45]	11.40 [+88.59, +88.60 , +88.58]	55.69 [+44.21, +44.10, +44.27]
With hyper-parameter Tuning (HT) - Random Search			
Autoencoder	0.69 [-0.35, -0.38, -0.29]	62.65 [-42.79, -39.87, -35.74]	79.01 [-20.99, -19.61, -17.68]
Decision Trees	40.08 [-39.25, -39.51, -39.01]	13.92 [+41.72, +79.85, +41.22]	56.95 [+19.17, +35.79, +19.32]
Gaussian Naive Bayes	33.33 [-31.19, -32.87, -32.79]	30.10 [+6.10, +14.10, +7.70]	66.20 [-0.10, -0.90, +0.20]
Isolation Forest	14.14 [-11.34, -13.56, -13.52]	16.28 [+14.83, +26.87, +33.72]	61.88 [+5.32, +2.22, +1.22]
KNN	39.36 [-27.31, -38.81, -33.82]	9.85 [+18.61, +83.49, +24.06]	54.92 [+9.26, +36.65, +11.88]
LightGBM	55.53 [-54.43, -54.97, -54.28]	16.15 [+64.16, +80.78, +61.85]	58.07 [+29.26, +36.15, +31.13]
Random Forest	44.80 [-9.58, -8.70, -5.30]	28.05 [+26.10, +0.90, +6.15]	81.11 [+8.09, +1.09, +5.09]
Robust Covariance	4.60 [-4.15, -4.10, -4.04]	20.15 [+8.95, +17.85, +29.55]	60.85 [+0.25, +0.75, +0.55]
XGBoost	78.34 [-77.09, +12.10, -77.78]	41.32 [+42.68, +58.68, +56.98]	89.55 [-0.05, +5.16, +5.15]
ADMXGB	93.33 [+6.48, +6.29, +6.62]	6.82 [+93.17, +93.18 , +93.16]	53.41 [+46.49, +46.38, +46.55]
With hyper-parameter Tuning (HT) - HyperOPT			
Autoencoder	0.72 [-0.35, -0.39, -0.30]	63.50 [-43.30, -40.10, -35.50]	79.15 [-20.65, -19.35, -17.25]
Decision Trees	45.25 [-44.33, -44.65, -44.15]	16.35 [+40.85, +78.25, +39.65]	58.90 [+18.65, +34.20, +18.10]
Gaussian Naive Bayes	34.13 [-31.83, -33.65, -32.57]	32.50 [+5.00, +12.40, +6.00]	67.10 [+0.70, -1.30, -0.40]
Isolation Forest	15.20 [-12.15, -14.61, -14.55]	18.12 [+13.88, +26.13, +33.88]	62.50 [+5.50, +1.80, +1.70]
KNN	38.10 [-25.55, -37.55, -32.48]	11.50 [+17.60, +82.30, +23.00]	55.50 [+9.10, +36.10, +11.40]
LightGBM	34.95 [-33.94, -34.40, -33.65]	12.48 [+69.91, +83.62, +66.52]	56.23 [+32.15, +37.57, +33.27]
Random Forest	50.22 [-14.22, -13.02, -10.22]	33.84 [+20.86, -4.69, +1.16]	84.00 [+5.40, -1.00, +2.50]
Robust Covariance	5.00 [-4.53, -4.48, -4.42]	22.90 [+7.10, +16.10, +28.10]	61.50 [+0.60, +0.80, +1.20]
XGBoost	0.54 [0.00, -0.01, +0.03]	98.50 [-0.37, +0.56, -0.10]	94.80 [-0.19, +0.11, +0.00]
ADMXGB	33.41 [+66.41, +66.21, +66.53]	15.87 [+84.12 , +84.03, +84.11]	57.90 [+42.00, +41.86, +42.06]